

SPECTRAL SIGNATURE OF CONTAMINATED WATER

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in Partial Fulfillment of the Requirements
for the Degree of
Master of Technology**

by

D. PRATHIBA

to the

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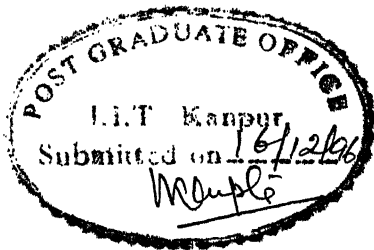
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It is certified that the work contained in this thesis entitled **SPECTRAL SIGNATURE OF CONTAMINATED WATER**, by Ms. D. Prathiba, has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Dec. 1996



**DEDICATED
TO
THEO**

*Who is a great source of
encouragement and inspiration to me*

ABSTRACT

In the country, water contamination is an acute problem which is increasing due to industrialization. The remote sensing data are being used in the evaluation of water quality. For the quantitative and qualitative evaluation of water quality using remote sensing data, proper selection of wavelength of satellite sensor is essential. In view of this, we have carried out experiments to study spectral reflectance characteristics of different water samples with varying concentration of contaminants (carbonate, chloride, fluoride, iodide, nitrate, phosphate and sulphate). The behavior and magnitude of the spectral reflectance is found to vary with the sources and the amount of contamination. Based on the detailed laboratory measurements, we have discussed appropriate wavelengths for identification of these contaminants and their concentration. Various empirical relationships between concentration of contaminants and their reflectance have been proposed. The present study will prove useful in the analysis of remote sensing data and in the estimation of concentration of contaminants in the water bodies.

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CHAPTER I

Introduction

1.1 General

Remote sensing has proved to be a potential tool in collecting information about the earth's natural resources and environment. Remote sensing techniques offer rapid and continuous assessment of different features, however, the analysis of remotely sensed data is often complex because of the changing conditions and surrounding environment. Remote sensing is not only a interdisciplinary field, but as a science it spans the spectrum from basic research to operational use. A successful remote sensing operation programme must be prepared to solve the maximum variety and complexity of applications.

From the past few decades man's understanding of the environment and his awareness of the danger of environmental pollution have increased enormously. The water pollution is one of the acute problems which affect the day to day life of mankind. The water covers about 75% of the surface of our earth which affects the weather, the atmosphere and the ecological situation in general. The sources of pollution in water bodies are due to natural as well as man made. Due to rapid growth of urbanization and industrialization, water quality is deteriorating day by day. Remote sensing techniques have been used to monitor various water quality parameters. Valuable information about quality can be achieved with remote sensing methods, because surface and subsurface water volumes of lakes and rivers show characteristic spectral signatures which are also modified by industrial contaminations. Suspended organic and inorganic particles and phytoplankton in water bodies can be easily identified by various remote sensing methods.

Remote sensing techniques have been used to map the quality of water surfaces (Topliss et al., 1988, Grunwald et al. 1988, Hamilton et al. 1993, Nichol 1993, Mertes et

al. 1993, Olbert et al. 1994). The qualitative analysis of water quality parameters are easy whereas the quantitative analysis is rather difficult. The presence of salt contamination and its estimation of concentration over large areas of water bodies using in situ sampling is lengthy, time consuming expensive and often inaccurate. The remotely sensed data measured by airborne and satellite sensors can provide an alternative, synoptic, speedy and economic methods for assessing various salt contaminations in reservoirs, lakes, rivers and coastal water. A sound knowledge of the form of the relationship between salt concentrations and reflectance for various types of salt is required for the quantitative analysis of airborne and satellite sensors data to be used successfully for estimation of concentration of contaminants. In the present study Shimadzu UV-VIS Spectrophotometer UV-160A is used to measure reflectance of water samples containing different types of contaminants. The UV-160A is a micro-computer controlled double-beam recording spectrophotometer with monochromator, key board, and graphic printer.

1.2 Objectives of the present work

The present thesis work is undertaken with the following objectives :

- i) To study the characteristics of spectral reflectance of water samples with different salt concentrations in the wavelength range 300 to 1100 nm of electromagnetic spectrum to study the effect of reflectance with the increase of salt concentrations.
- iii) To study the effect of temperature on spectral reflection of water with varying contaminants.
- iv) To develop empirical relationships between reflectance and various types of salt concentrations.

v) To study the spectral reflectance characteristics of Ganga water at various sites and to develop an empirical relation between reflectance and suspended solids.

1.3 Organization of Thesis work

The present thesis has been divided into six chapters. Besides this introductory chapter, Chapter II deals with remote sensing techniques. Chapter III deals with the sources of pollutants to surface and ground water and their impact on mankind. In Chapter IV we have discussed the experimental techniques and details of sample preparation. The characteristics of the spectral reflectance and their nature of variations in the wavelength range 300 to 1100 nm have been discussed in Chapter V. The conclusion of present study has been given in chapter VI

CHAPTER II

Remote Sensing

2.1 Introduction

Remote sensing is the science and art of obtaining information about an object, area or phenomenon through the analysis of data acquired by a device that is not in contact with the object, area, or phenomenon under investigation (Lillesand and Kiefer 1979). The analysis and interpretation of a remotely sensed data requires understanding of interaction of electromagnetic radiations with the object and its various parameters.

The estimation of water quality parameters from space is based on the spectral reflectance of sunlight by suspended or dissolved materials in the upper water column. The spectral reflectance of the water is wavelength dependent and the choice of appropriate wavelength bands is very important in the monitoring of water quality. The reflected radiations in visible, near infrared and middle infrared wavebands, emitted radiations in middle and thermal infrared wavebands, and reflected radiations in microwave bands are commonly used for monitoring of water quality. In the present chapter, a review of interaction of electromagnetic radiations with water and application of remote sensing in monitoring various water quality parameters has been discussed.

2.2 Remote sensing system

A remote sensing system using electromagnetic radiations has four components: source, earth surface interaction, atmospheric interaction and sensor, these components are described briefly below.

Source: The source of electromagnetic radiation includes natural radiations from sun reflected or the earth's emitted radiation from earth, or man made radiations.

Earth's surface interaction

The amount and characteristics of radiation emitted or reflected from the earth surface is dependent upon the characteristics of the objects on the earth's surface.

Atmospheric interaction: Electromagnetic radiations incident on the earth surface or reflected from the earth surface pass through the atmosphere. Radiations while coming from the earth surface or after reflection or emitted radiations from the earth's surfaces interact through atmosphere. Due to interaction with atmosphere, the radiations are highly distorted and also get reflected and scattered.

Sensor: The electromagnetic radiations after its interaction with the surface of the earth and the atmosphere, energy is recorded by the sensor board on satellite or airborne platforms.

2.3 Active and passive remote sensing systems

An active remote sensing system supplies its own source of energy, which is directed towards the object in order to measure the returned or reflected energy. A passive remote sensing system records energy naturally radiated or reflected from an object.

2.4 Remote sensing techniques

In remote sensing technique, the most common and useful wave bands are visible and near infrared region (400 to 1100 nm) for passive type of sensors and in radar and microwave region (10^6 to 10^9 Hz) for active type of sensors. Various type of sensors are classified, as given below

- (i) Multispectral sensor
- (ii) Thermal sensor
- (iii) Microwave and radar sensor

Remote sensing techniques are classified into three types based on the type of sensor platform as follows:

- (a) Airborne sensing
- (b) Satellite remote sensing
- (c) Multiband ground truth radiometer

2.5 Electromagnetic energy

The link between the components of the remote sensing system is electromagnetic energy. The energy is transferred in three ways, conduction, convection and radiation. In remote sensing we are concerned only about energy transfer by means of radiation. This energy behaves in accordance with basic electromagnetic wave theory. This wave theory describes electromagnetic energy as traveling in a harmonic, sinusoidal fashion. Electromagnetic energy consists of electric and magnetic fields, which are orthogonally perpendicular to each other.

2.6 Electromagnetic spectrum

Electromagnetic spectrum extends from cosmic rays at the extremely short wavelength to low-frequency radio waves at the long-wavelength end as shown in the fig (2.1). In remote sensing visible and near infrared radiations in the wavelength range 0.4-3.0 μm , infrared radiations in the wave length range 3-14 μm and microwave radiation in the wavelength range 5-500 mm are widely used.

2.7 Energy interaction in the water body

When electromagnetic energy is incident on any given earth surface feature, three fundamental energy interactions are possible which is illustrated in fig (2.2). For an element of the volume of a water body, various fractions of the energy incident on the element are reflected, absorbed and transmitted. Applying the principle of energy, we can state the inter-relationship between these three energy interactions as

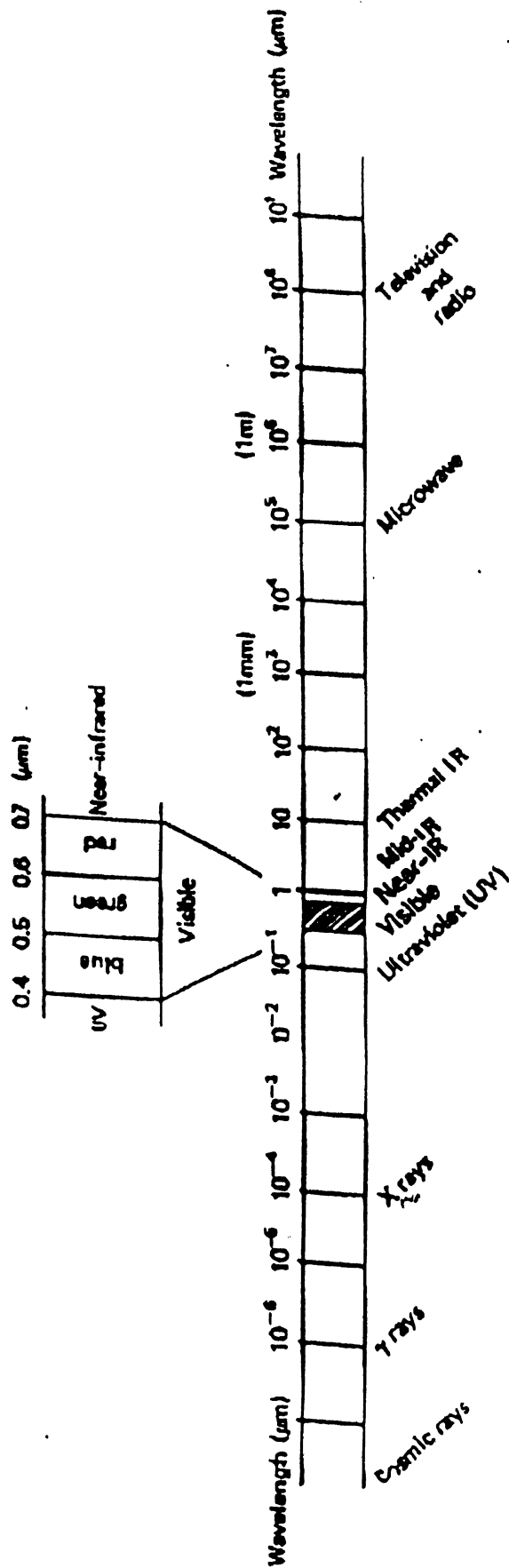


Fig. 2.1 The electromagnetic spectrum

$$E_I(\lambda) = E_R(\lambda) + E_A(\lambda) + E_T(\lambda) \quad (2.1)$$

Where E_I is incident energy

E_R is reflected energy

E_A is absorbed energy

E_T is transmitted energy

Two basic concepts are related with eq (1)

- 1) The properties of energy reflected, absorbed and transmitted which vary for different earth features depending on their material type and physical parameters.
- 2) The proportion of reflected, absorbed and transmitted energy is highly dependent on wavelength.

Thus, depending on this concepts two features may be indistinguishable in one to another wavelength.

The electromagnetic radiation reaches on the water surface or water bodies from the sun comprises direct solar irradiance (E_{sun}) and diffuse irradiance (E_{sky}) as shown in fig (2.3). This irradiance fall with a zenith angle θ_0 on to the water surface (S) where it is specularly reflected ($r\theta_0$) and also transmitted into the water bodies.

2.8 Spectral reflectance

The reflectance characteristics of earth surface features may be quantified by measuring portion of incident energy that is reflected. This is measured as a function of wavelength and is called spectral reflectance $\rho(\lambda)$. It is mathematically represented as

$$\rho(\lambda) = E_R(\lambda) / E_I(\lambda) \quad (2.2)$$

where $\rho(\lambda)$ is expressed as a percentage.

A graph of the spectral reflectance of an object as a function of wavelength is termed as spectral reflectance curve.

Different target materials in general have spectral reflectance curves of different shapes and this forms a basis for identifying materials from remotely sensed data and

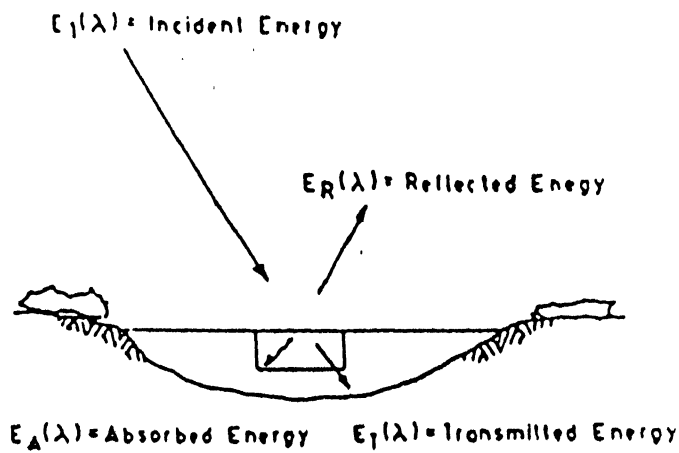


Fig. 2.2 Basic interactions between EMR and water surface feature
(after Lillesand and Kiefer, 1994)

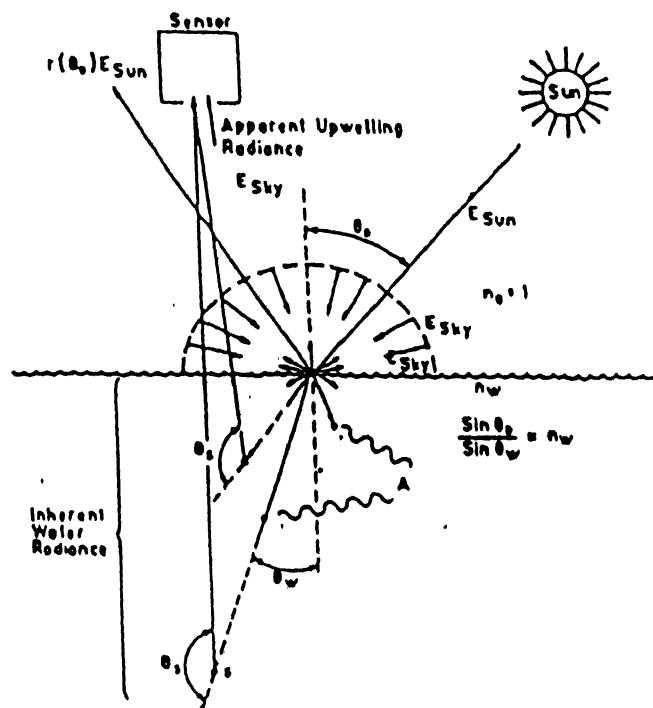


Fig. 2.3 Interaction of EMR with water
(after Curran and Novo, 1988)

developing sensors with appropriate wavelength ranges. The shape of spectral reflectance curve of a given material is often called its spectral signature.

The spectral distribution of the surface radiance $Wm^{-1} \cdot Sr^{-1} \mu m^{-1}$ depends on both the spectral reflectance of the surface $\rho(\lambda)$ and incident irradiance $E(\lambda)$ in $Wm^{-2} \mu m^{-1}$. It is mathematically represented as

$$\rho(\lambda) = \pi 4\lambda / E(\lambda) \quad (2.3)$$

2.9 Factors affecting spectral reflectance of water body

The spectral reflectance of water body depends on many factors such as suspended solids concentration, water depth, atmosphere, sensing geometry, water/atmospheric boundary and aquatic components. These are described briefly in the following sections:

2.9.1 Suspended solid concentration

The sensitivity of the reflectance depends on the extent of concentration of the suspended solids. The relationship between reflected solar radiation and suspended solid concentration in surface water has been established by many researchers (Gitelson et al. 1993, Bhargava and Mariam., 1990, Ritchie et al. 1976). The reflectance increases with the increase in the concentration of the suspended solids but decreases as its size increases (Bhargava and Mariam, 1991).

In order to suppress the environmental influence on the measurement of suspended solid concentration by remotely sensed data, the radiance measurement should be taken when sky is clear i.e., around noon and at a time of moderate solar zenith angle 30 to 60 degrees (Ritchie et al. 1976). In addition to this the sensor should be looking off-vertical and away from the plane of the sun to avoid sun glint.

2.9.2 Water depth

The sensitivity of spectral reflectance depends on water depth of the water body. Fig (2.4) shows the spectral distribution curve for the near infrared and visible radiations at 20 m depth of water surface. At this point visible light, mainly blue is present and near infrared gets totally absorbed. fig (2.5) shows the reflection taking from the shallow water.

The effect of water depth on the suspended solids measurement will vary with bottom material and the type of suspended solids (Khorram and Heather. 1985). However, it is only in very clear and shallow water that the materials at bottom makes a significant contribution to the reflectance properties at the water surface.

2.9.3 Atmosphere

The spectral reflectance is more sensitive to atmosphere. Only small fraction of solar irradiance incident on water body is reflected. So atmospheric scattering can account for over 95% of the signal received by sensor when recording over clean deep water (Moore 1989). The blue and green wavelength that are ideal for the remote sensing of suspended solid concentration are most affected by the atmosphere scattering. Therefore, measurements of suspended solids is greatly affected by the atmospheric scattering. To use the remotely sensed data for the estimation of suspended solids, atmospheric effects must be suppressed (Chen et al. 1992).

2.9.4 Sensing geometry

The angle at which the radiation reaches on the water surface and to the sensor determines the degree of correlation between suspended solid concentration and reflectance. In water bodies the radiance is strongly related to solar zenith angle (θ) degree as shown in the fig (2.6). When sun is lower than 50 degree in the sky, water surface radiance starts to make a significant contribution to the signals detected by the sensor.

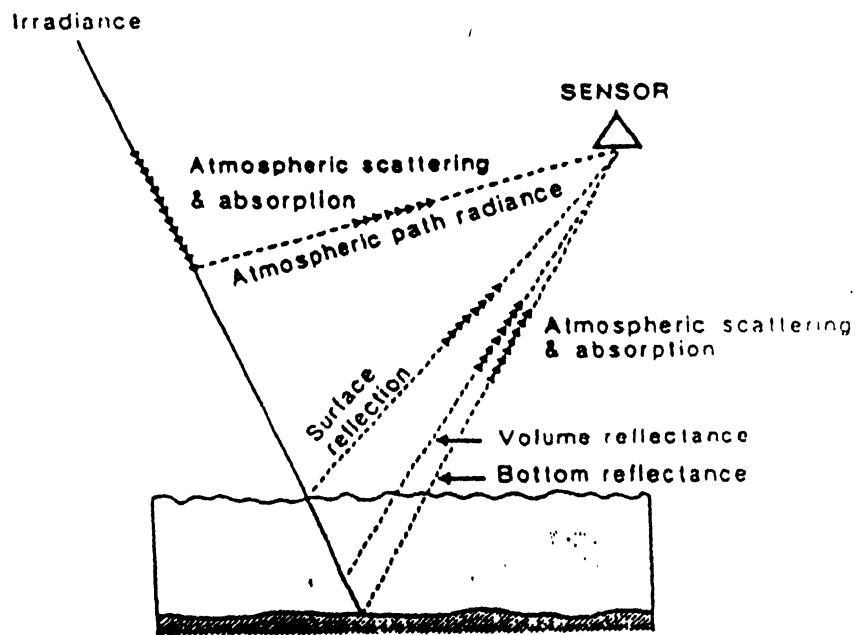


Fig. 2.4 Processes acting on solar radiant energy in the visible part of the spectrum over an area of shallow water (after Mather, 1987)

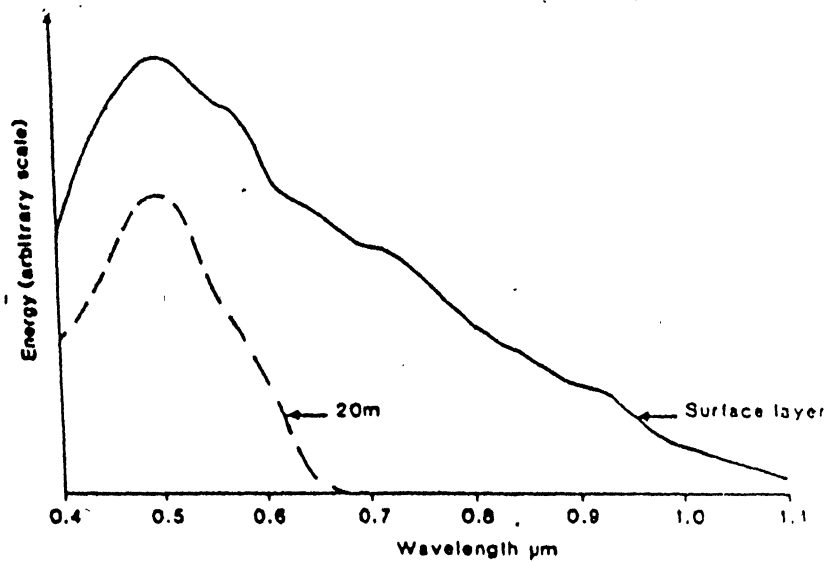


Fig. 2.5 Spectral reflectance curve for surface water layer (after Mather, 1987)
 — (Surface water layer) - - - (20m depth)

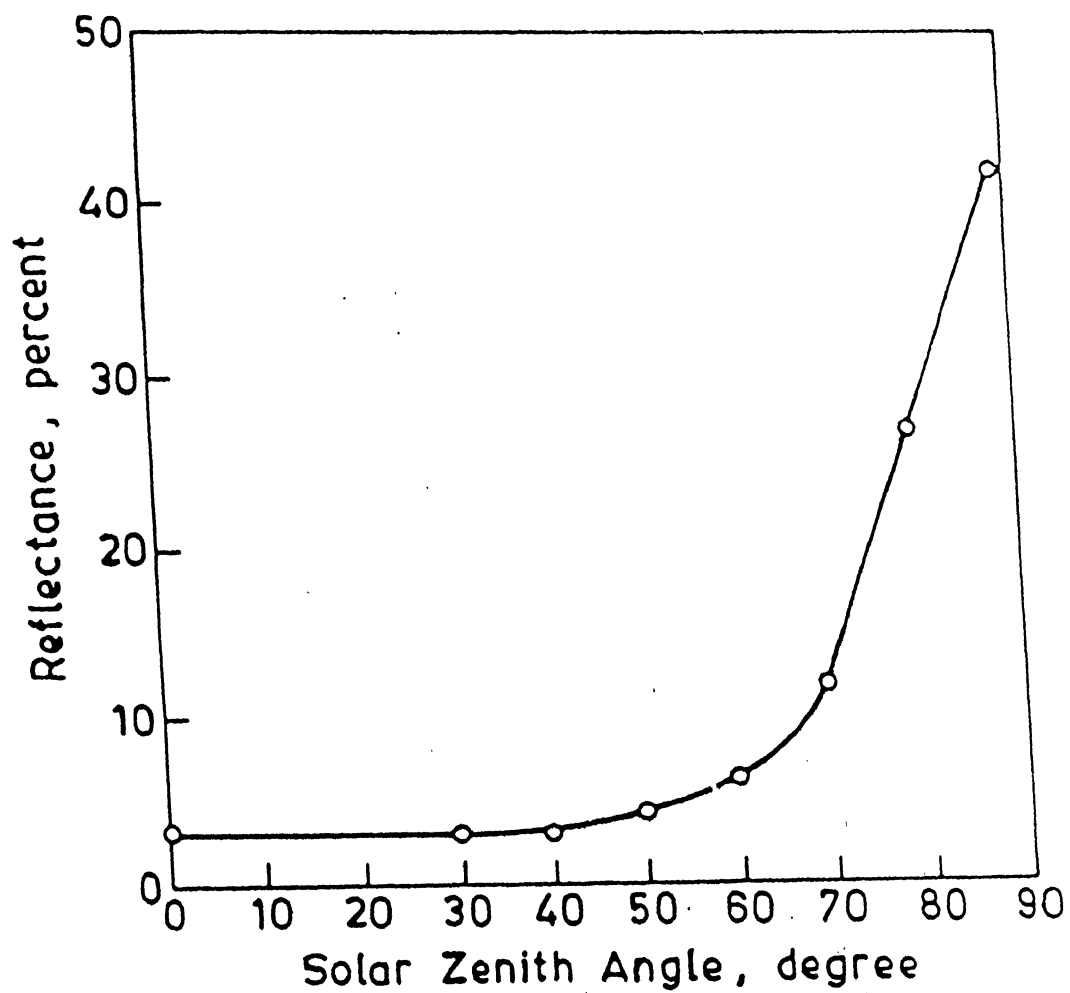


Fig. 2.6 Effect of Solar Zenith Angle on reflectance.
(after : Curran and Novo, 1988)

Thus, for this reason solar zenith angle around 40 - 50 degrees are often chosen in the studies of the suspended solids concentration by radiance.

2.9.5 Water /Atmosphere boundary

The amount and the character of the radiation that enters and leaves the water depends on the water/atmosphere boundary. The water/atmosphere boundary has an influence on the relationship between suspended solid concentration and radiance. However, several researchers have noted that for practical purposes if the sensor is viewing vertically then the influence of this boundary will be minimum (Ritche et al 1976).

2.9.6 Aquatic components

All surface water supplies supports growth of minute aquatic organisms. The free swimming and floating organisms are called plankton. The plankton's are composed of animals zooplankton and phytoplankton. The later is predominantly algae which contains chlorophyll. In most of the water bodies suspended solids are present along with phytoplankton and dissolved organic matters. It is difficult to separate the contribution of each to the total observed reflectance. Phytoplankton measurements made in blue and red bands can determine the presence of phytoplankton due to presence of chlorophyll. With the increase in chlorophyll concentration absorption of blue light increases and scattering increases in green wavelength (Lillesand and Kiefer 1994).

2.10 Application of remote sensing in monitoring water quality

The remote sensing technique is unlikely to ever match the accuracy of ground based measurement. However, they are capable of providing spatial variability which can never be appreciated from the ground based conventional methods. The estimation of water quality parameters from space is based on the adsorption and scattering of sunlight by suspended or dissolved materials in the water bodies. The following water quality

parameters such as suspended solid concentration, turbidity, phytoplankton and algae, oil and industrial pollution can be determined as explained briefly below :

2.10.1 Suspended particles

Suspended solids is the single most pollutant of water bodies which has very high visual impact on consumers. In clear water transmitted energy is greater and in turn the reflected energy will be reduced. Due to the presence of suspended particles, the transmitted energy will be greatly reduced and depending on the parameters of the suspended sediment properties to absorb the energy, the reflectance energy will vary. The percentage reflectance increases with the concentration of suspended sediments concentration for all particle sizes and for all soil types at all wavelengths in the range of 500 to 1000 nm. (Bhargava and Mariam 1991). Soil type characteristics and particle size play a dominant role in affecting the reflection characteristics of a suspension. Reflectance increases with decrease of particle size.

The use of derivative spectroscopy to estimate suspended solid concentration has been evaluated using reflectance spectra recorded by spectroradiometers. Three regions of the spectrum at wavelengths around 450 - 550, 675 - 750, and 800 - 1000 nm show particularly large changes in derivative reflectance with suspended solid concentration and these are therefore recommended spectral regions for the estimation of suspended solid concentration with derivative spectroscopy (Chen et al. 1992).

2.10.2 Turbidity

Turbidity may be caused by a wide variety of suspended materials which range in the size from colloidal to coarse dispersion, depending upon the degree of turbulence. Industrial waste liberated into water bodies have large amounts of organic substances and other inorganic substances which produce turbidity. Several investigators have used remote sensing to monitor water turbidity both qualitatively and quantitatively (Harlem et

al. 1984, Lindell 1981). The percentage reflectance increases with turbidity for all particle sizes for all soil types at all wavelengths in the range of 500 to 1000 nm (Bhargava and Mariam 1991). The spectral region 700 to 900 nm wavelength range can be used to get information about a wide range of turbidity levels and some properties (such as organic content, specific gravity) of turbidity causing materials present in the water body. In wavelength range 550 to 750 nm, materials with higher organic content have lower reflectance values than those materials with lower organic content.

2.10.3 Phytoplankton and algae

Inorganic nutrients such as nitrogen and phosphorus present in waste water discharges and agricultural runoff stimulate the growth of algae and phytoplankton which contributes to eutrophication of water bodies. The algae and phytoplankton which contain chlorophyll can be detected from remote sensed data. The existence of a quantitative relationship between reflected solar radiation and chlorophyll concentration in surface water is studied by a number of researchers (Dekker 1993, Prasad 1993, Torres et al. 1992). When chlorophyll concentration increases a shift of the peak position from about 680 to 715 nm and an increase of the peak magnitude will occurs. The magnitude and peak position can be used for determining the phytoplankton concentration (Gitelson 1993). With increasing amounts of algae biomass the reflectance decreases in the blue to green spectral regions giving a small peak at green wavelength and increased in red to infrared range specially near 700 nm (Arenz et al. 1996).

2.10.4 Oil / Industrial / Thermal pollution

In water bodies, oil pollution is caused mainly due to pipeline leakage and accidental spillage. With the help of remote sensing, we can monitor the magnitude of the oil spill and also the direction of the drift of the spill oil. Visible and ultra-violet regions of electromagnetic spectrum can be used to detect oil pollution. As thermal infrared

emittance of water is higher than that of the oil, thermal infrared scanner is used to detect oil pollution with day and night capabilities. Radar is effective in high sea states with day-night capabilities.

Thermal infrared remote sensing can be used to detect industrial and municipal waste discharges in the water bodies due to temperature differences in effluent and receiving water. Using thermal infrared scanner temperature measurement can be carried out. Temperature difference up to 0.5°C may be detected by using thermal infrared imaginary. This can operate day and night under any atmospheric conditions (Sharma 1987).

CHAPTER III

Sources of Pollutants

3.1 Introduction

The envelop of water on and near the earth's surface is called hydrosphere. It consists of ocean, lake, river and underground water. Out of 1500 km² of water present in the hydrosphere, merely 1 percent is available for fulfillment of human needs and which is available from such sources as ground water, rivers, lakes, soil profile, atmosphere and biological system. The irony is that whereas the requirement of water for various purposes is increasing at a fast rate, but due to increase of pollution level the availability of water qualities becoming scarce. In the present chapter, a review of sources and type of water pollution is discussed.

3.2 Water Pollution

The term pollution refers to the deterioration in chemical, physical and biological properties of water brought by human activities and also by natural processes which induce decomposed vegetable material and weathering products of rocks, etc., in the water resources (Southwick, 1976). In wider perspective, water pollution may be defined as the alteration in physical, chemical and biological characteristics of water which may cause harmful effects on human and aquatic life. Because of inter-dependence of physical, chemical and biological characteristics, addition of organic waste affects simultaneously chemical properties, color, odor and biological properties. Due to pollution, significant changes in physical properties of water, such as : color, odor, turbidity, taste and temperature is found which lead to acidic, alkaline and saline nature of water owing to the suspended chemical substances.

3.3 Surface water pollution

The major contributors to pollution of rivers, streams, lakes and coastal water are sewage, huge quantity of municipal and domestic wastes, variety of industrial effluents, atmospheric dissolved gases, decomposed animals and vegetable materials and weathered solid and rock materials, etc. The sewage containing organic waste, excessive nutrients like nitrates and phosphates, help to increase various decomposers (bacteria and fungi) in water bodies resulting in the pollution. The phosphates, nitrates and also ammonia compounds originates from detergents and fertilizers which flow into streams with rain water and results in excessive growth of algae, a source of deoxygenation of water and emittance of foul smell. The inert suspension of fine particles of dust, clay soil, ores etc., and mixing of acids, alkalis, phenols, copper, lead, zinc mercury, insecticides and fungicides, sulphides and sulphites and various ferrous salts also account for a water pollution.

The nature and intensity of water pollution is linked with many factors like waste water disposal and treatment system, hydrological conditions of diluting bodies and self purification capacity of the streams, characteristics of effluents discharging from an area, socio-economic conditions of the communities generating the waste and, in cases, types of soil and vegetation.

3.4 Ground water pollution

The pollution of ground water resources has also caused great concern. The sources of pollutants are in the form of F^- , Cl^- , hardness, etc. The level of pollution is, characteristics (texture, structure) of the soils, nature of rainfall and depth of the water table, etc. The area with sandy soils and high water table is more prone to pollution from soluble substances. The seepage from polluted tanks, lakes are streams and infiltration of contaminated water liquids from refuse dumps in low lying areas are also sources of pollution, especially in sandy types of soils, where pollution can effect well waters up to

the depths over 400 meters (Saxena et al., 1977). The various sources of pollution are given in the table 3.1.

Table 3.1 (after Knox et al., 1996)

Source	Source in a category
Agricultural	Agricultural Agricultural activities (application of pesticide and fertilizers) Agricultural (manure and fertilizers) cattle raising Dairy farm Farming Grain storage facility Irrigation Pesticide application Pesticide storage and disposal
Hazardous waste sites	Abandoned hazardous waste sites Hazardous waste sites Hazardous liquid disposal Gasoline disposal Supervened hazardous waste sites TCE disposal Accidental spill
Land spills	Industrial landfill Land fill Solid waste disposal facility Sanitary landfill Waste disposal sites
Industrial operations	Gas company Industrial Liquid transport pipeline Refinery
Septic tank systems	Solvent in septic tanks Septic tanks Cess pools
Oil and gas field activities	Abandoned oil and gas field Drilling company Injection well for brine disposal Improperly abandoned well in oil and gas field Oil field brine Oil production

Urban land use	Oil and gas recovery well
	Oil drilling operation
	Salt water disposal
	Commercial sites
	Golf course
Under ground storage tanks	Over development
	Residential
	Urban land use
	Underground storage tanks
Mining	Acid mine drainage
	Mine tailings pile
	Mining
Road salt application	Road salt application
	Salt storage handling facility

3.5 Occurrence of chlorides

Chlorides occur in all natural water in widely varying concentration. The chloride content normally increases as the mineral content increases. Upland and mountain supplies usually are quite low in chlorides, whereas rivers and ground water usually have a considerable amount. Sea and ocean water represents the residues resulting from partial evaporation of natural water that flow into them and chloride levels are very high.

Chlorides gain access to natural water in many ways. The solvent power of water dissolves chlorides from top soils and deeper formations. Ground water in areas adjacent to the oceans are in hydrostatic balance with sea water. Excessive pumping of ground water produces a differences in hydrostatic head in favor of the sea water and it intrudes in the fresh water area. Human excreta, particularly the urine contain chlorides in an amount about equal to the chlorides consumed with food and water. Many industrial wastes contain appreciable amounts of chlorides.

3.5.1 Public health significance of chlorides

Chlorides in reasonable concentrations are not harmful to human. Concentrations above 250 mg/l give salty taste of water. Chlorides are generally limited to 250 mg/l in

water supplies intended for public use. In many areas of the world where water supplies are scarce, sources containing as much as 2000 mg/l are used for domestic purposes with the development of adverse effects, once the human system becomes adapted to the water

3.6 Occurrence of fluorides

The solvent power of water dissolves fluorides from fluorine bearing minerals. Fluorine is an active element known, it forms simple fluoride compounds and many complex ions. The principle form in which fluoride is added to water bodies are NaF, CaF_2 , H_2F_2 . In some areas, particularly in the neighborhood of aluminum processing plants, contamination of the atmosphere and vegetation by the fluorides has been a serious problem.

3.6.1 Public health significance of fluorides

Approximately 1 mg/l of fluoride ion is desirable in the public water for the optimal dental health. The excessive fluorides level in drinking water causes mottled enamel. The mottling appears with excess of the fluoride ion concentration by 1.0 mg/l and the degree and the severity of the mottling increased as the fluoride level increases.

3.7 Occurrence of nitrates

The compounds of nitrogen are of great interest to the environmental engineers because of importance of nitrogen compounds in the atmosphere and in the life process of all the plants and the animals. The nitrogen compounds found in the underground water is represented by the NO_2^- , NO_3^- , and NH_4^+ ions. In case they are inorganic in origin, they are believed to be harmless from the sanitary point of view, whereas the same ions of organic origin. i.e. those derived from the decay of organic matter, may indicate the pollution of water and the possible presence of the pathogenic bacteria. The NO_2^- , NO_3^- and NH_4^+ ions are particularly abundant in the water coming from the dug well tapping

shallow ground water in the polluted places where there is no clay screen preventing the water from being polluted from the surface.

Fertilizers and pesticides contain nitrates. Excessive amount of nitrates are carried away in the water percolating through the soil because the soil does not have the ability to hold them. This frequently results in relatively high concentrations of the nitrates in the ground water and surface water.

3.7.1 Public health significance of nitrates

The environmental protection agency for drinking water nitrate concentration in the terms of nitrogen should not exceed 10 mg/l in the public water supplies. It has been found that drinking water with high nitrate content often caused methemoglobinemia in infants. The presence of NO_2^- ions in the underground water used for drinking is not possible, in the case of extremity, only the traces of these ions are permissible.

3.8 Occurrence of phosphates

The presence of phosphate is source for eutrophication of water bodies, which in turn influence the environment. The organic compounds of phosphorous of significance of engineering practice are the phosphates or their molecularly dehydrated forms usually referred to as polyphosphates or condensed phosphates. Organically bond phosphorus is usually a minor consideration.

Domestic waste water is relatively rich in phosphorus compounds. Prior to the development of the synthetic detergents, the content of inorganic phosphorus usually ranges from 2 to 3 mg/l and the organic forms varies from 0.5 to 1.0 mg/l. Most of the inorganic phosphorus is contributed by human wastes as a result of the metabolic breakdown of proteins and the elimination of liberated phosphates in the urine. The synthetic detergents designed for the house market contain large amounts of polyphosphates as builders. Many of them contain from 12 to 13% phosphorus or over

50% of the polyphosphates. The use of these materials as a substitute soap has greatly increased the phosphorus content of the domestic waste water which intern polluted the water bodies.

3.8.1 Public health significance of phosphates

Phosphorus and nitrogen are both essential for the growth of algae. When both nitrogen and phosphorus are plentiful algal blooms occur which may result in pollution in the water bodies. The algal blooms do not occur when phosphorus or nitrogen or both present in very limited amounts. The critical level for inorganic phosphorus is 0.005 mg/l or 5 mg/l under summer growing conditions.

3.9 Occurrence of sulphates

The sulphate ion is one of the major anions occurring in the natural waters. Sulphate ions are abundant in underground waters, especially in those having low salinity. In contrast with the chloride ions, the sulphate ion contents of underground waters are limited by the Ca_2^+ ions, which combines with the sulphate ion to form CaSO_4 , which is hardly soluble. The accumulation of sulphates in water may results from dissolution of gypsum and anhydrite, as well as from oxidation of various sulphide minerals like pyrite, etc.

3.9.1 Public health significance of sulphates

It is of importance in the public water supplies because of its cathartic effect to human beings when it is present in excessive amounts. For this reason the recommended upper limit is 250 mg/l in water intended for human consumption's. Sulphates are important in both public and industrial water supply because of the tendency of the water containing appreciable amounts to form hard scales in boilers and heat exchangers. Sulphates also create problems in handling and treatment of waste waters. These are odor

and sewer-corrosion problems resulting from the reduction of sulphates to hydrogen sulphide under anaerobic conditions.

3.10 Occurrence of iodides

Usually small quantity (micro-gram-per-liter) of iodine is present in most natural water. Higher concentrations may be found in brines, certain industrial wastes treated with iodine. Because of hydrolysis, active iodine exists in the form of elemental I_2 hypiodous acid HOI or a form there of, hypo iodide ion OI^- and in the excess iodide, the trioxide ion I_3^- .

3.10.1 Public health significance of iodides

Iodine is used to disinfect certain potable and swimming pool water. The deficiency or the excess of certain minor constituents like iodine in water may lead to diseases. Among them the most widespread is the endemic goiter resulting from the environmental deficiency of iodine. Endemic goiter is a disease characterized by a tumor like enlargement of the thyroid gland.

3.11 Occurrence of carbonates

Carbonate occur in natural water due to weathering action of carbonate bearing rocks. The physical evidence of this type of weathering is the well know cavernous zones in limestone. Surface water containing large amounts of algae contains appreciable amounts of carbonates due to higher levels of pH values. Boiler water, chemically treated water, particularly those produced in lime or lime-soda ash softening of water contains large amounts of carbonates causing the alkalinity of the water.

3.11.1 Public health significance of carbonates

Presence of carbonate has little public health significance. Water containing higher amounts of carbonates causes alkalinity and usually unpalatable and consumers tends to seek other supplies. Carbonate water causes scales in the boilers.

3.12 Tap water composition of IIT Kanpur

The table (3.2) gives the composition of tap water of IIT Kanpur campus.

Table (3.2)
(after Prasad, 1986)

Turbidity	Not detectable
pH	8.0
Total dissolved solids	435 mg/l
Bicarbonate alkalinity	470.6 mg/l as CaCO_3
Carbonate alkalinity	4.4 mg/l as CaCO_3
Total hardness	182 mg/l as CaCO_3
Carbonate hardness	182 mg/l as CaCO_3
Non carbonate hardness	0 mg/l as CaCO_3
Calcium hardness	60 mg/l as CaCO_3
Magnesium hardness	122 mg/l as CaCO_3
Chloride	15 mg/l as Cl^-
Sulphate	32 mg/l as SO_4^{2-}

CHAPTER IV

Description of experimental technique and sample preparation

4.1 Introduction

For the measurements of spectral reflectance of solids and liquids, numerous instruments are available. These instruments are used to measure spectral reflectance in the field and in the laboratory. Spectral reflectance measurements in the laboratory is rather difficult compared to the field since the physical conditions of the material is not easily achieved. In the present chapter we have given details about the preparation of the water samples with various types and varying degrees of contamination. We have also given details of the experimental technique used in the present study.

4.2 Experimental methodology

Laboratory studies on the spectral properties of water are notoriously difficult to perform and are less developed than those for vegetation and soil. However, laboratory experiments have been designed to control the same variables while stimulating at least the major radiations characteristics of a lake or ocean (Whitlock et al., 1982, Novo et al., 1989, Bhargava and Mariam 1990).

For the quantitative and qualitative evaluation of the water quality using remote sensing data, proper selection of wavelength of satellite sensor is essential. In view of this, we have carried out detailed measurements of transmittance and absorption of water samples of various salts with varying anion concentration. From the transmittance and absorption, reflectance have been calculated using equation given in the earlier chapter.

4.3 Details of Spectrophotometer

Shimadzu UV-VIS Spectrophotometer UV-160A has been used to measure transmittance and absorption values of sample solution. The UV- 160A is a micro-computer controlled double-beam recording spectrophotometer with following features.

- i) Compact instrument combined with monochromator, key board, and graphic printer.
- ii) 24 single-function keys for easy operation.
- iii) Scanning speed up to 2400 nm/min, which greatly reduces measuring time.
- iv) It incorporates many standard calculation programs such as data determination at a fixed wavelength, automatic quantitative analysis by two to three wavelengths calculation or derivative values, kinetic measurement, and multi-component analysis.
- v) It permits various spectral processing such as the expansion, compression of spectra, measuring the peak, derivative, smoothing, data storage, and arithmetic calculation between spectra.

4.3.1 Specifications

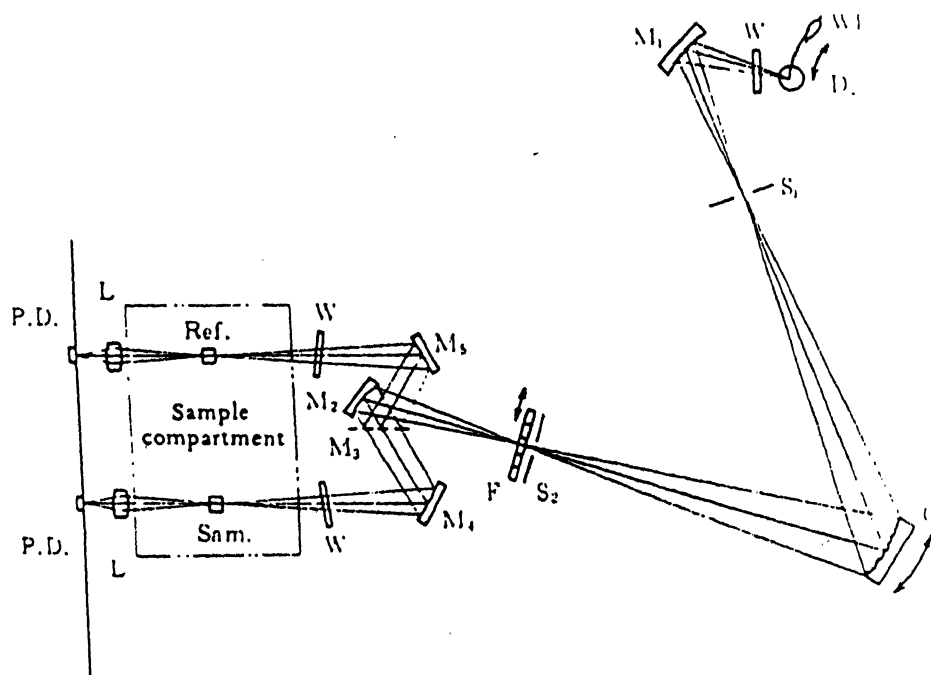
The specification of spectrophotometer are given in the table (4.1)

Table (4.1)	
Measuring wavelength range	200 to 1100 nm
Spectral band width (resolution)	2 nm
Wavelength readability (wavelength setting)	0.1 nm increment
Wavelength accuracy	+0.5 nm or -0.5 nm, with automatic wavelength correction
Wavelength reproducibility	+0.1 nm or -0.1 nm, when being set from the longer wave length side
Wavelength scanning speed	Monochromator setting speed is nearly 3600 nm/min Fast nearly 2400 nm/min Medium nearly 1500 nm/min Slow nearly 480 nm/min
Sampling interval	Automatic setting according to wavelength ranges 900 nm $\geq \lambda$ ranges > 500 nm (1 nm) 500 nm $\geq \lambda$ ranges > 200 nm (0.5 nm)

	200 nm $\geq \lambda$ ranges > 100 nm (0.2 nm)
	100 nm $\geq \lambda$ ranges ≥ 10 nm (0.1 nm)
Light source switching	Automatic switching according to wavelengths Any light source can be selected between 295 and 346 nm
Photometric system	Double beam system
Baseline correction	Automatic correction with computer memory (after turning on the power). Recorrection is possible
Recording mode	Print out of measured data and calculated results Drawing of spectra and other curves with printout of parameters and data.
Spectrum processing	Data memory, with two channels for overlapping, subtraction and division between channels Expansion and compression Peak detection Differentiation (for derivative) or smoothing Data output at regular intervals of wavelength or time
Light source	50 W long-life halogen lamp (2000 hrs.), and socket type deuterium lamp (500 hrs.) with automatic control of maximum sensitivity
Monochromator	Aberration-corrected concave holographic grating with $f = 4.2$.
Recorder	Computer controlled thermal graphic printer.
Power requirement	With line voltage selector for 100, 115, 220, and 240 V
Sample compartment	Inner size: 110 mm wide, 230 mm deep and 105 mm high Optical path length of the cell: up to 100 mm
Size	630 mm wide, 500 mm deep and 450 mm high.
Weight	42 Kg
Ambient atmosphere	Room temperature 15 to 35° C with humidities of 45 to 80%, with less than 70% humidity for more than 30° C

4.3.2 Optical system

The light beam emitted from the light source (deuterium lamp D₂ or halogen lamp WI) is reflected by the mirror M₁, as shown in the fig (4.1) and directed into the monochromator. The light source position is automatically controlled for maximum sensitivity and the light source condenser mirror is located outside the light source housing



D ₂	: Deuterium lamp	W	: window plate
W ₁	: Halogen lamp	M ₁ ~M ₅	: Mirrors, M ₃ is a half mirror
F	: Filter	L	: Lens
G	: Grating	Sam	: Sample cell
S ₁	: Entrance slit	Ref.	: Reference cell
S ₂	: Exit slit	P.D.	: Photodiode

Fig. 4.1 Optical System of spectrophotometer

so as not to be exposed to heat and ozone. All the optical elements excluding the light source are sealed from the external atmosphere by the window plate W so as to be dust free. The slit width of the monochromator is fixed at 2 nm. The grating is a Shimadzu-made 900 lines/mm aberration-corrected concave holographic grating. The light beam coming from the monochromator is passed through the stray-light cut-off filter F, reflected by the mirror M_2 , and then split by the half mirror M_3 into the sample and reference beams. Each beam passes through the respective cell to the detector (photo-diode).

4.3.3 Spectrum mode

In this mode of the spectrophotometer the values of a measured spectrum are printed out at regular wavelength intervals in the range of 200 to 1100 nm. The wavelength interval is chosen within the range of 1 to 99 nm. We can set the wavelength scanning speed to fast, medium, slow as required. And finally the data can be copied automatically with computer controlled thermal graphic printer.

4.4 Sample preparation and experiment procedure

Water samples with different salt solutions have been prepared for measuring reflectance values. In this study, we have taken 7 different types of water samples with varying concentrations of

- i) Na_2CO_3 for preparing water with carbonate concentration sample,
- ii) NaCl for preparing water with chloride concentration sample,
- iii) NaF for preparing water with fluoride concentration sample,
- iv) CaI_2 for preparing water with iodide concentration sample,
- v) KNO_3 for preparing water with nitrate concentration sample,
- vi) $\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$ for preparing water with phosphate concentration sample, and
- vii) Na_2SO_4 for preparing water with sulphate concentration sample

The molecular weight of different salts are given in the table (4.2)

Table 4.2

Salt sample	Molecular weight g/l
Na_2CO_3	128.98
NaCl	58.44
NaF	41.99
CaI_2	366.23
KNO_3	101.1
$\text{Na}_3\text{PO}_4 \cdot 12\text{H}_2\text{O}$	380.13
Na_2SO_4	142.04

Depending on the molecular weight the amount of salt required for particular anion concentration is calculated and weighed using ^{any} electronic balance. The sample solutions have been prepared with thoroughly weighed salt and measured water volumes. All the above mentioned salts are found to dissolved in distill^{ed} water and gave color^{less} solutions. Sample solutions of seven different salts with different anion concentration have been prepared. By using spectrophotometer, transmittance and absorption values of different water samples have been measured as described below :

About 3 ml of sample solution is taken in the cell of spectrophotometer. Sample cells used for the determination of spectra in solution vary in path length from 1 to 10 cm. The sample cell used is made of quartz and size of the cell 1 cm square. The cell containing the sample was kept in the sample compartment. Transmittance was measured in percentage in the wavelength range 300 to 1100 nm. Absorption is measured in ABS in the region between 300 to 1100 nm. The transmittance and absorption values have been

measured at three different temperatures 10° , 30° and 50° C. From the measured transmittance and absorption values, we have calculated the reflectance using eq (2.1) as discussed in chapter II.

4.5 Ganga water

Water samples from Ganga river near Bithour, at three different places have been collected. The three different places are (1) Druvtila, (2) Hari-Dham, (3) Bramhawart. Bithour is 12 Km from IIT campus of Kanpur. Suspended solid concentrations of these samples have been measured experimentally in the environmental engineering laboratory and their values have been correlated with their reflectance values obtained using spectrophotometer and the experimental procedure have been discussed in the next section.

4.5.1 Measurement of suspended solids

The apparatus used for measuring the suspended solids are evaporating dishes (porcelain, 90 mm diameter), drying oven (operating at 103 to 105° C), desiccator (provided with a desiccant containing a colour indicator of moisture concentration), analytical balance 200 g capacity capable of weighing up to 0.1 mg.

Glass-fiber filter was kept in the oven for four hours to remove the moisture content and it was cooled keeping it in the desiccator for 1 hour. The weight of the empty filter paper was measured using analytical balance. This gave the value of the dry filter paper (B). The well mixed 50 ml of Ganga water sample was taken and filtered using the filter paper. After the filtration the non filterable residue along with filter paper was kept in the drying oven keeping it in the evaporating dish. The temperature in the oven was maintained at 105° C. The residue is dried for 24 hours and then cooled keeping it in the desiccator for 2 hours. The weight of this will give the weight of the residue along with the filter paper (A). The total suspended solid weight in mg/l is measured by using the formula

Total suspended solids = $((A-B) * 1000) / \text{Volume of the sample taken in liters}$

Using spectrophotometer transmittance and absorption measurements have been made for three Ganga samples at two different temperatures 30 and 50^o C. The reflectance values are calculated using eq (2.1) discussed in chapter II. Reflectance values obtained by using spectrophotometer and total suspended concentration obtained from experiment have been correlated, the results have been discussed in the next chapter.

CHAPTER V

Results and Discussion

5.1 Introduction

Estimation of water quality parameters from space is based on the spectral reflectance of light from the upper water column. This is possible if we have a priori information about the spectral characteristics of dissolved/suspended contaminants present in water bodies. The objective of the present study is to choose appropriate wavelength suitable for monitoring water quality parameters. The present work consists of two parts i) measurement of reflectance values for dissolved salt samples prepared in the lab and ii) laboratory measurement of reflectance of Ganga water and determination of suspended solid concentrations. The results have been presented and discussed in this chapter.

5.2 Spectral response of dissolved salts

The water samples have been prepared in the lab with varying concentrations for different type of salts: carbonates, chlorides, fluorides, iodides, nitrates, phosphates, and sulphates. These salts have been found to dissolve in distilled^{ed} water and gave colorless solutions containing dissolved solids. The reflectance characteristics of dissolved solids in water can be quantified by measuring the portion of incident energy that is reflected. The transmittance and absorption values have been measured using spectrophotometer and reflectance has been calculated using eq. (2.1). Reflectance of an object as a function of wavelength is termed as spectral reflectance. Different salt water samples in general show spectral reflectance of different shapes and this forms a basis for identifying the type of salts from remotely sensed data. Spectral reflectance curves have been drawn for different salts with varying concentrations. A graph has been plotted taking the percentage reflectance on y-axis and wavelength measured in nm on x-axis at an intervals of 50 nm.

The empirical relationships have also been developed between dissolved solid concentrations and percentage reflectance. The spectral response of these water samples have been described briefly in following sections.

5.3 Spectral response of carbonate contamination

Water samples with varying concentrations of carbonate, 1200, 1800 and 3600 mg/l, have been prepared in the lab. The spectral reflectance of these samples have been measured at a constant temperature 30° C in the wavelength range 300 to 1100 nm at an interval of 50 nm with the help of spectrophotometer. We have also shown the reflectance of tap water for comparison. Spectral reflectance curve of tap water is almost coinciding with the other curves of carbonate with varying concentrations (fig 5.1). In the wavelength range 750 to 850 nm, slight variation in reflectance curve of carbonate contaminated water and tap water is seen. In the wavelength range 700 to 850 nm, the reflectance decreases with the increase of carbonate concentration. The variation of reflectance with varying concentrations of carbonate is highly wavelength dependent and nature of variation is found to be cyclic. Reflectance of carbonate with varying concentrations and tap water vary in the range of 4 -10%. The higher reflectance and higher contrast in reflectance are seen in the wavelength range 300 to 500 nm. In the wavelength range 500 to 900 nm, reflectance shows variation in the range 5 - 7%. In the wavelength range 900 to 1100 nm, sharp difference in the reflectance is seen between tap water and with varying concentrations of carbonate. In the wavelength range 300 -1100 nm, reflectance curves are characterized by maxima and minima peaks. The number of peaks increases with the increase of carbonate concentrations. For 1200 mg/l of carbonate concentration, two distinct peaks are seen in the wavelength range 450 to 800 nm. Using linear regression analysis, we have found following empirical relation

$$Y = 0.001X + 4.69 \quad (5.1)$$

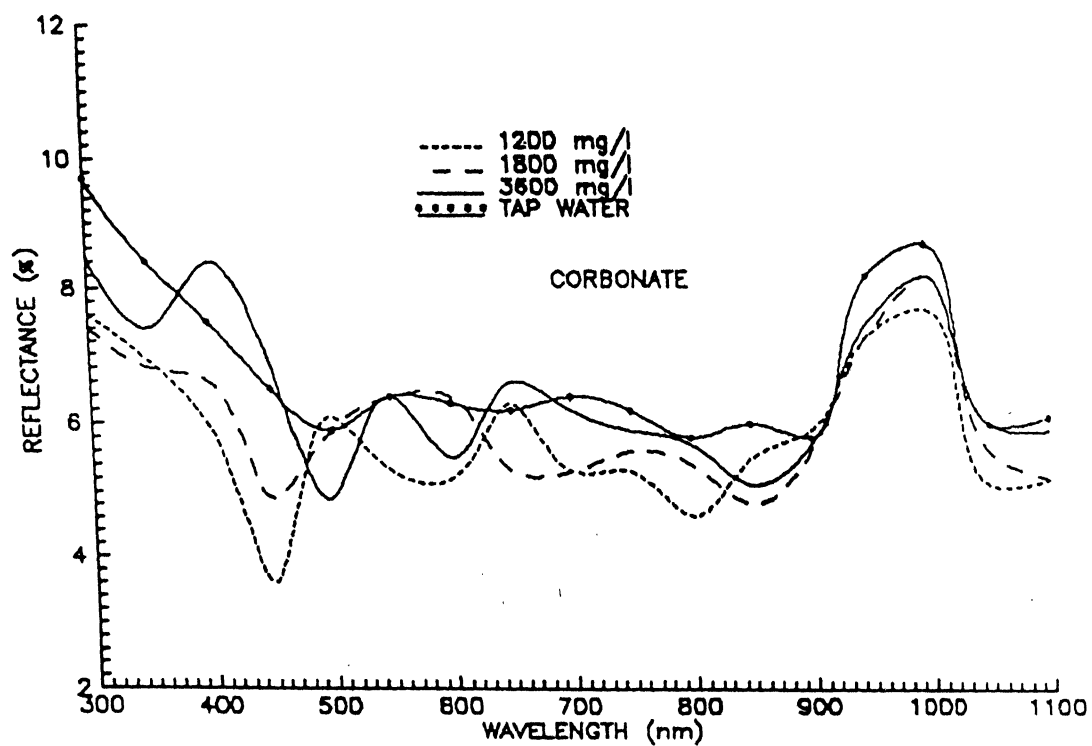


Fig. 5.1 Spectral reflectance of carbonate containing water samples with varying concentration at 30°C.

The above equation shows linear relation of reflectance with carbonate concentrations (fig 5.2) at wavelength 400 nm. This relation seems to be valid for the carbonate concentration in the range 1200 to 3600 mg/l. At other wavelengths empirical relation can not be developed since the reflectance shows very irregular behavior and the reflectance contrast is not found to be significant.

5.4 Spectral response of chloride contamination

Effect of increasing chloride concentrations in water on reflectance is shown in the fig (5.3). The reflectance of chloride concentration in water varies in the range 4 - 8% and do not show significant wavelength dependence. The behavior of reflectance for 900 and 1200 mg/l is found to be similar. The maxima and minima peaks show one to one correspondence for 900 and 1200 mg/l concentrations in the broad wavelength range 300 to 1100 nm. The increasing concentration of chlorides up to 2400 mg/l show very distinct nature. The reflectance values have been found very close for the chloride concentrations of 900 and 1200 mg/l. However, the minima and maxima peaks do not show any correlation of peaks for chloride concentrations of 900 and 1200 mg/l. For higher concentration of chlorides, frequency of maxima and minima peaks increases in the wavelength range 300 to 700 nm. In the wavelength range 700 to 1100 nm, nature of the reflectance curves are found to be very similar. The reflectance curves of chloride concentrations show characteristic nature specially in the wavelength range 300 to 700 nm. The reflectance curves for chloride concentrations do not show particular nature except in the range 420-520 nm where the decreasing trend is seen with the increasing chloride concentrations. From fig (5.3) it is seen that the reflectance of the chloride water samples is lower compared to those of tap water. The effect of temperature on reflectance for chloride concentration of 900 mg/l is shown in fig (5.4). Not any particular nature of reflectance curves with varying temperatures is seen in particular except the frequency of minima and maxima peaks increase with the increasing temperatures (fig 5.4). At around

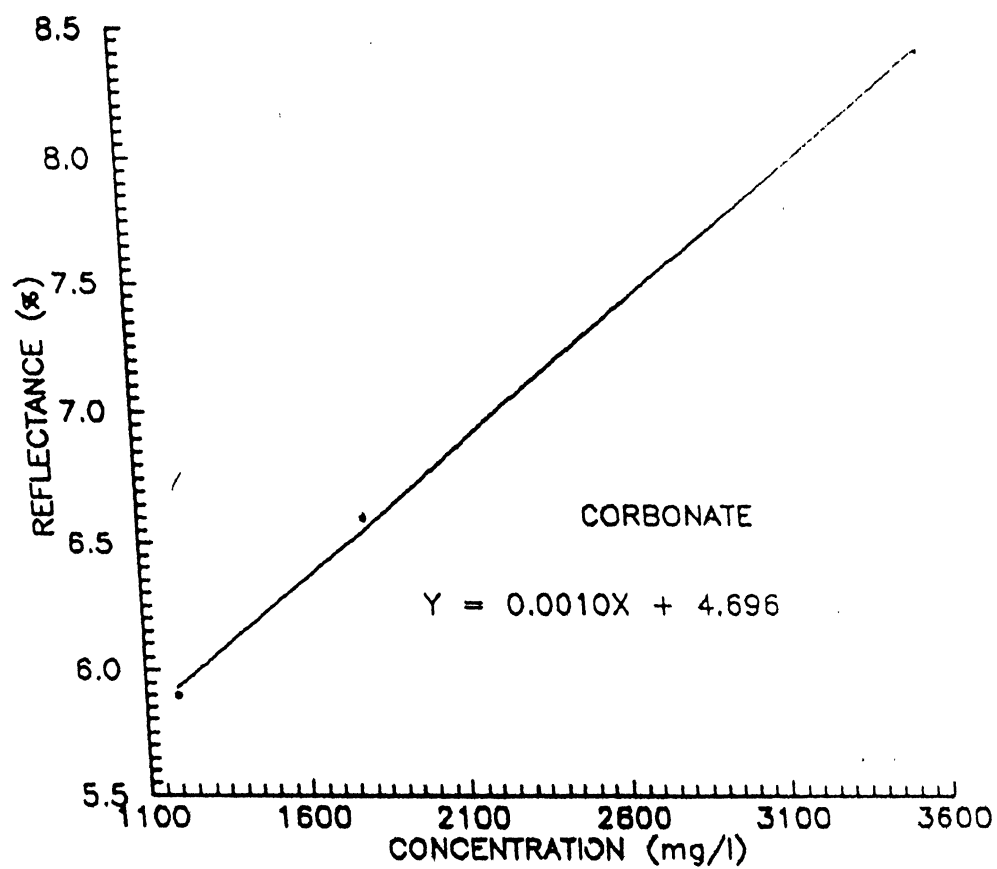


Fig. 5.2 Variation of reflectance of water with carbonate concentration at wavelength 400 nm.

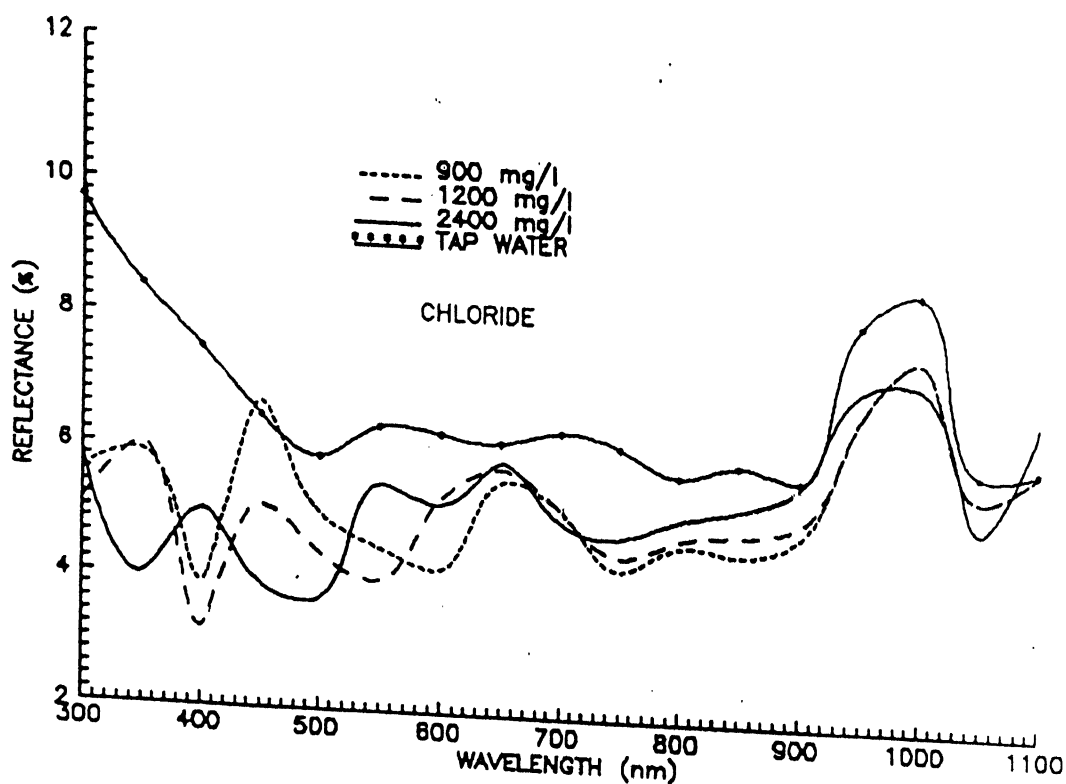


Fig. 5.3 Spectral reflectance of chloride containing water samples with varying concentration at 30°C

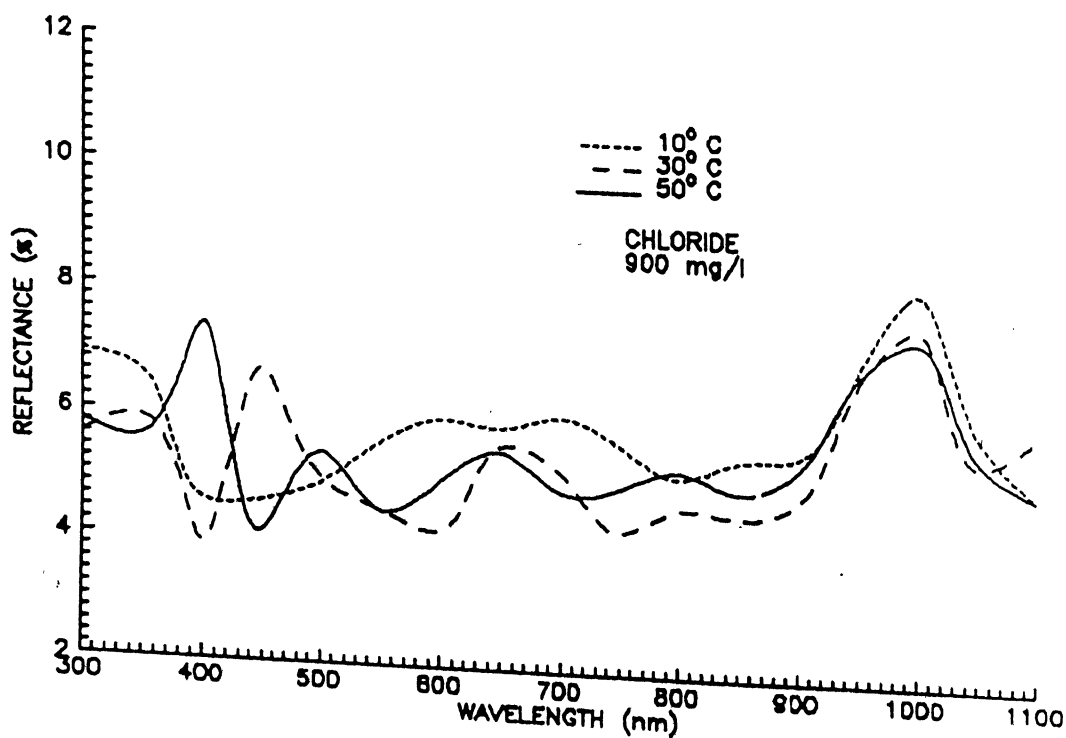


Fig. 5.4 Spectral reflectance of chloride containing water samples with varying temperature

1000 nm wavelength the reflectance shows decrease in reflectance value with increase of temperature.

The reflectance with chloride concentrations 900, 1200, 2400 and 3600 mg/l for wavelength 750 nm at 30° C is shown in the fig (5.5). We have found following empirical relation after regression analysis

$$Y = -9.5808E - 8X^2 + 0.0006X + 3.828 \quad (5.2)$$

The above relation shows non-linear behavior of reflectance with the increase of chloride concentrations.

5.5 Spectral response of fluoride contamination

Fig (5.6) shows reflectance curve for 600 mg/l of fluoride concentration which shows low reflectance values in almost all wavelength range 300 to 1100 nm. The reflectance of 900 mg/l of fluoride concentration is more compared to 600 mg/l concentration in almost in whole wavelength range except wavelength range 600 to 750 nm. The reflectance contrast is very small for 900 and 1200 mg/l of fluoride concentrations in wavelength range 300 to 1100 nm. It has been found that the reflectance becomes insensitive after some optimal limit of fluoride concentration. The variation in reflectance with varying fluoride concentrations is not uniform in measured wavelength range. In the wavelength range 350 to 600 nm, we have found increasing trend of reflectance with the increasing fluoride concentrations. The reflectance curves for fluoride concentrations and tap water do not show any significant reflectance contrast in the wavelength range 500 to 900 nm. The effect of temperature on reflectance for fluoride concentration of 900 mg/l is shown in the fig (5.7). In the wavelength range 700 to 1100 nm, reflectance has been found insensitive to temperature variations. In the wavelength range 400 to 550 nm shifting of minima peaks has been found with increase in temperature. The reflectance

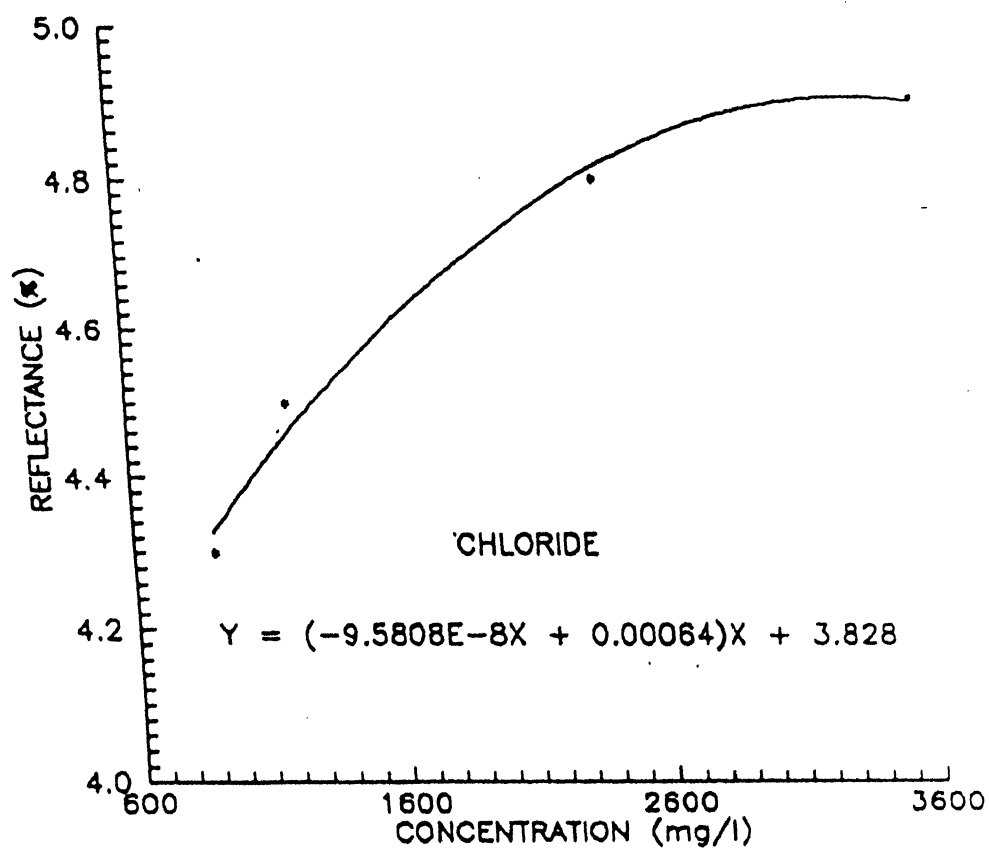


Fig. 5.5 Variation of reflectance of water with chloride concentration at wavelength 750 nm.

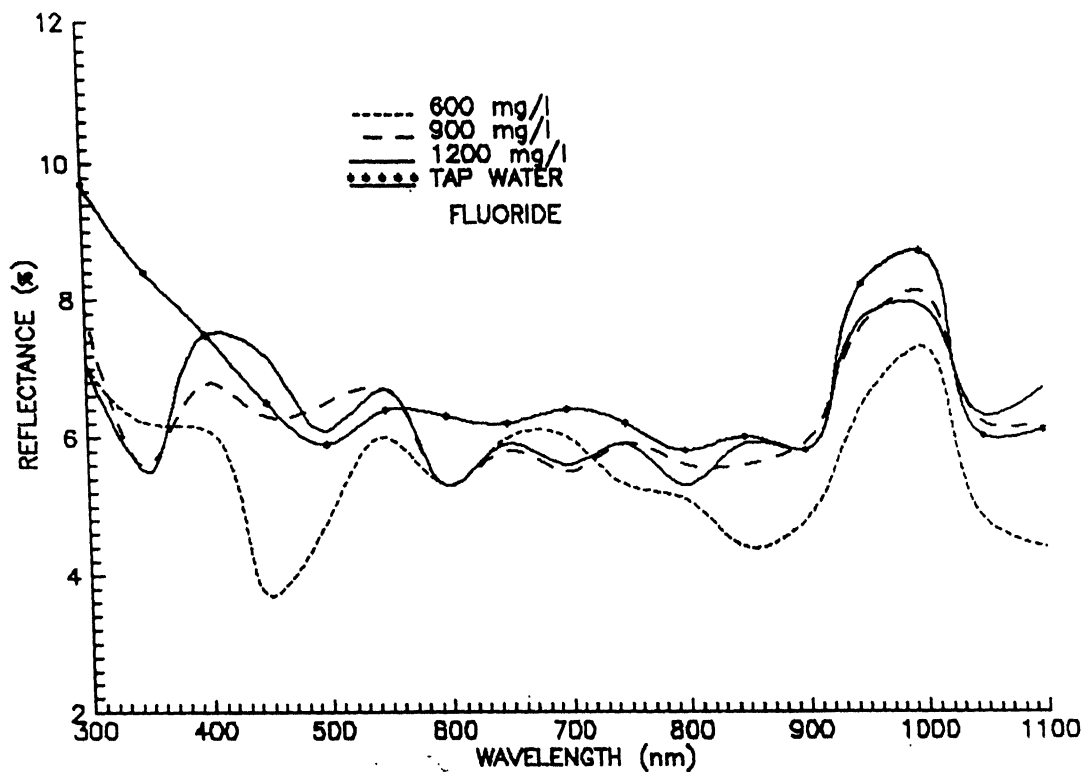


Fig. 5.6 Spectral reflectance of fluoride containing water sample with varying concentration at 30°C.

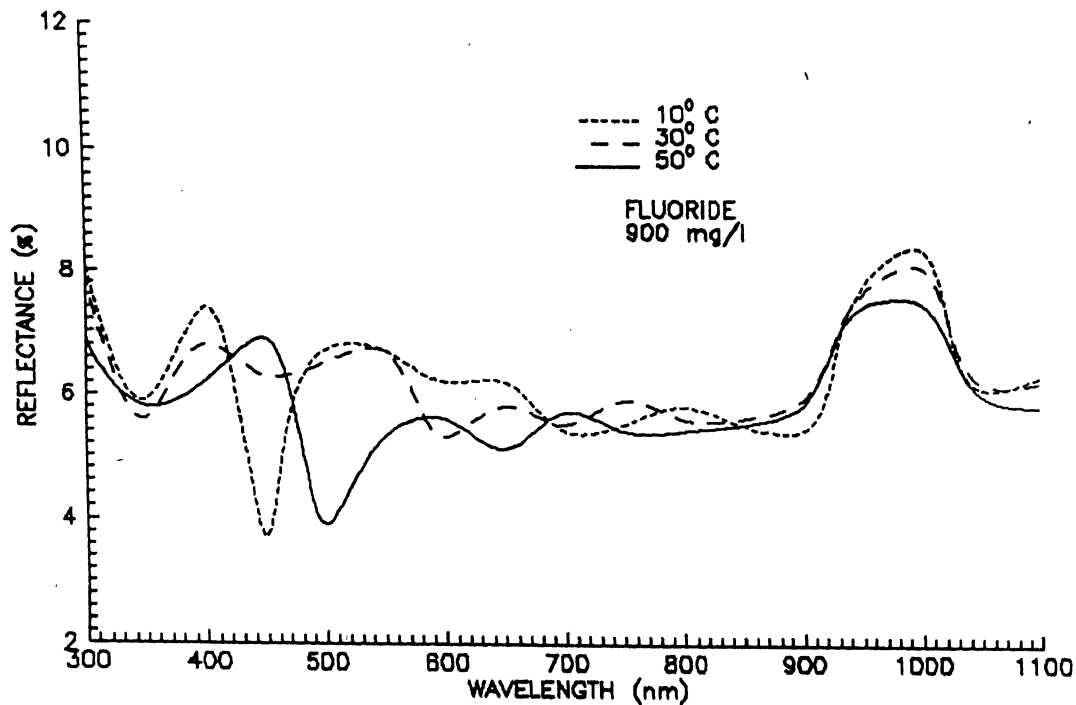


Fig. 5.7 Spectral reflectance of fluoride containing water samples with varying temperature

with fluoride concentrations 600, 900, 1200 mg/l for wavelength 400 nm at 30^o C is shown in the fig (5.8). We have found following empirical relation after regression analysis

$$Y = 0.0023X + 4.7 \quad (5.3)$$

The above relation shows linear behavior of reflectance with increase of fluoride concentrations.

5.6 Spectral reflectance of iodide contamination

Spectral reflectance for varying iodide concentrations is shown in fig (5.9) at 30^o C. In the wavelength range 300 to 500 nm, the nature of the reflectance curves is found to be very similar. For low iodide concentration (600 mg/l) a broad peak is seen in the wavelength range 350 to 500 nm. This peak sharpens with increase of iodide concentrations and the magnitude of reflectance increases. The reflectance peaks show one to one correlation in the wavelength range (350 to 500 nm), such correlation is also seen in the wavelength range 900 to 1100 nm. In the wavelength range 700 to 900 nm the reflectance curves of varying concentrations of iodide and tap water show significant contrast but the nature of the curves are found to be similar. The effect of temperature on reflectance for iodide concentration of 900 mg/l is shown in the fig (5.10). The variation of reflectance with temperature has been found negligible in the range 300 to 1100 nm. At wavelength 1000 nm, we have found increase in reflectance as temperature increases. A plot between reflectance and varying iodide concentrations for wavelength 400 nm at 30^o C is shown in fig (5.11). Using regression analysis we have found following linear empirical relation

$$Y = 0.0025X + 5.58 \quad (5.4)$$

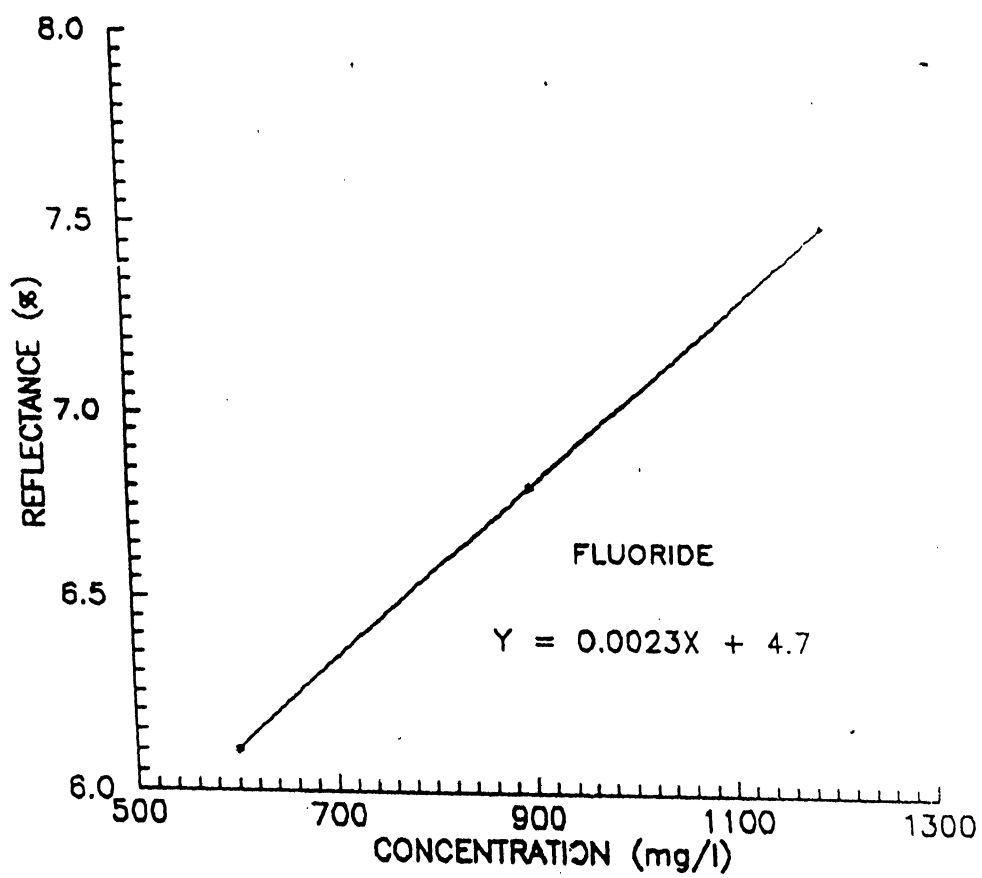


Fig. 5.8 Variation of reflectance of water with fluoride concentration at wavelength 400 nm

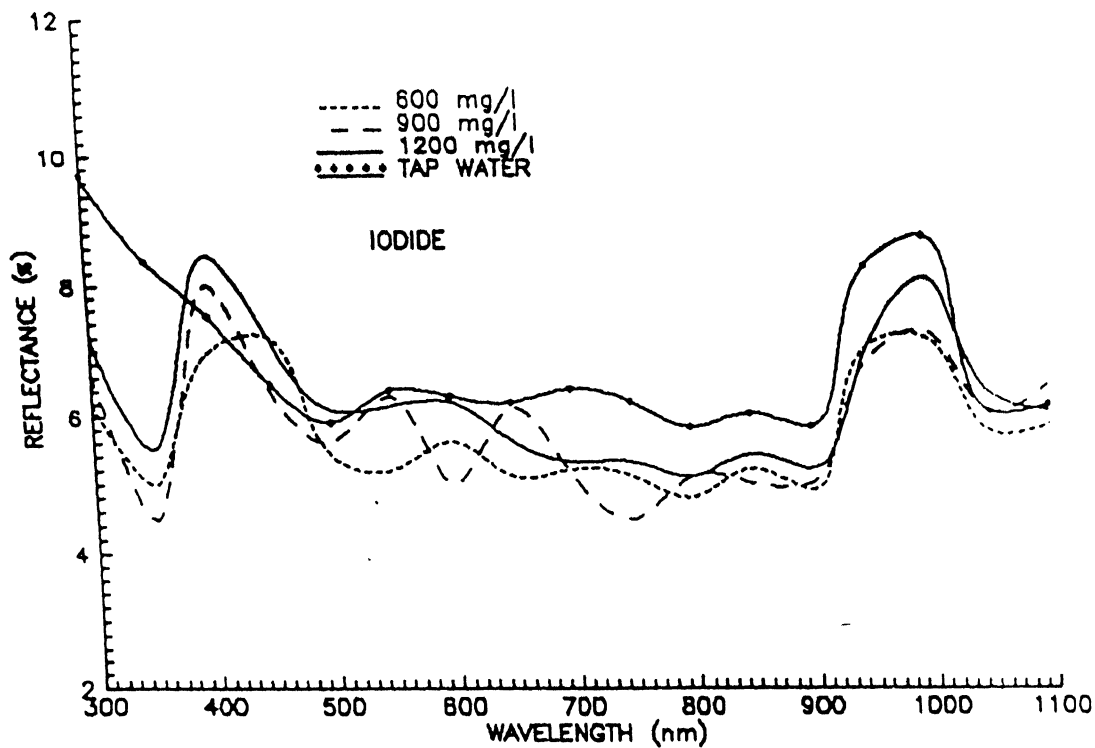


Fig. 5.9 Spectral reflectance of iodide containing water samples with varying concentration at 30°C.

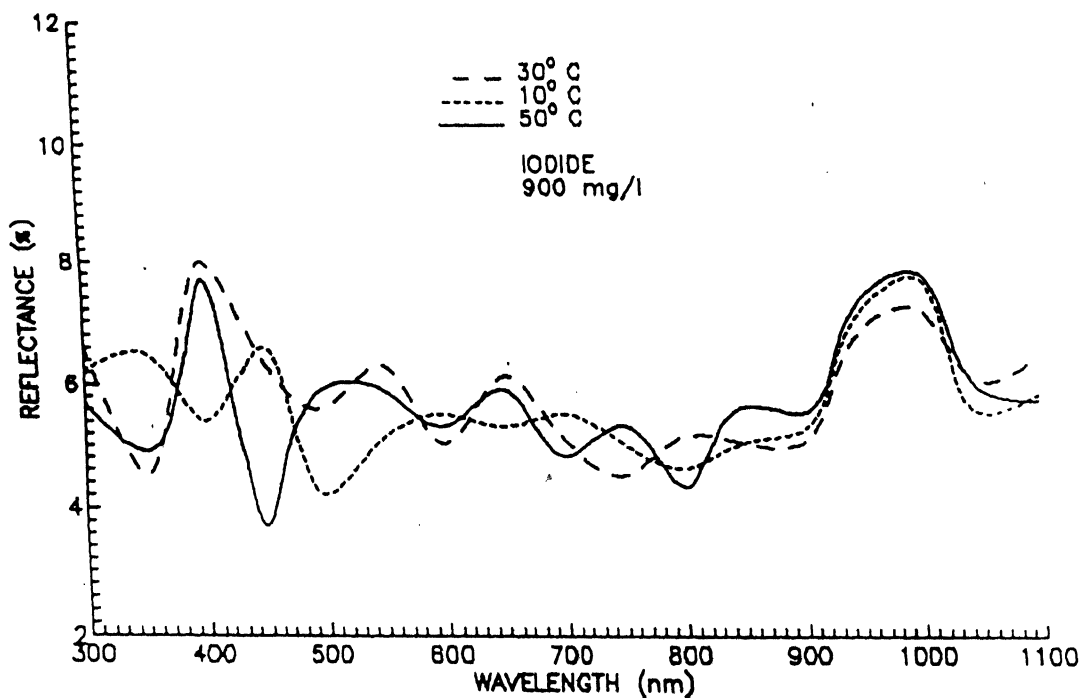


Fig. 5.10 Spectral reflectance of iodide containing water samples with varying temperature

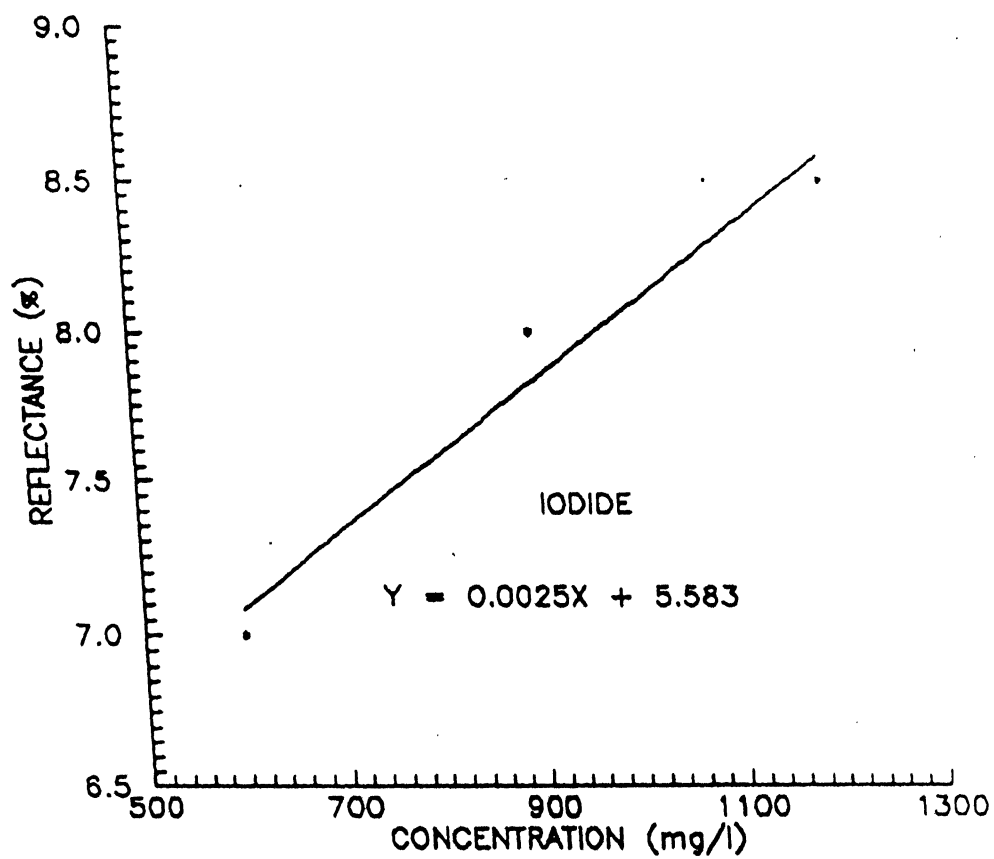


Fig. 5.11 Variation of reflectance of water with iodide concentration at wavelength 650 nm.

5.7 Spectral response of nitrate contamination

In fig (5.12), we have shown the spectral reflectance of water with varying nitrate concentrations 900, 1200 and 1800 mg/l and also of tap water. The reflectance of water with nitrate concentrations shows characteristic maxima and minima peaks in the wavelength range 300 to 600 nm. In other wavelength range 600 to 1100 nm the spectral response is not pronounced and it is difficult to distinguish between water samples of different nitrate concentrations. The reflectance of tap water is also similar to the water samples with different concentrations in the wavelength range 600 to 1100 nm but in the wavelength range 750 to 800 nm reflectance of tap water is distinctly seen. A graph is plotted between reflectance of water sample with 900 mg/l nitrate concentration at different temperature as shown in the fig (5.13). The variation of reflectance curves is almost uniform in the wavelength range 650 to 1100 nm and the variation in reflectance is very less. The variation in reflectance in the range 300 to 550 nm is highly variable but the trend of reflectance variation with temperature is not systematic. The characteristic nature of reflectance is seen in the wavelength range 600 to 700 nm, in this range the reflectance is found to decrease with temperature. In the wavelength range 300 to 600 nm the reflectance curves are characterized by minima and maxima peaks. These peaks show characteristic feature of a particular temperature. The empirical relationship is developed between percentage reflectance and nitrate concentrations. Fig (5.14) shows variation of reflectance with nitrate concentrations for wavelength 550 nm at 30^o C. By using regression analysis we have found following empirical relation

$$Y = 0.00084X + 4.39 \quad (5.5)$$

5.8 Spectral response of phosphate contamination

Water samples with varying phosphate concentrations, 600, 900, 1200 and 2400 mg/l have been prepared. Fig (5.15) shows spectral reflectance curves for water samples with varying phosphate contaminations. The reflectance curves show almost no effect of phosphate concentrations. In the wavelength range 450 to 550 nm, we have found

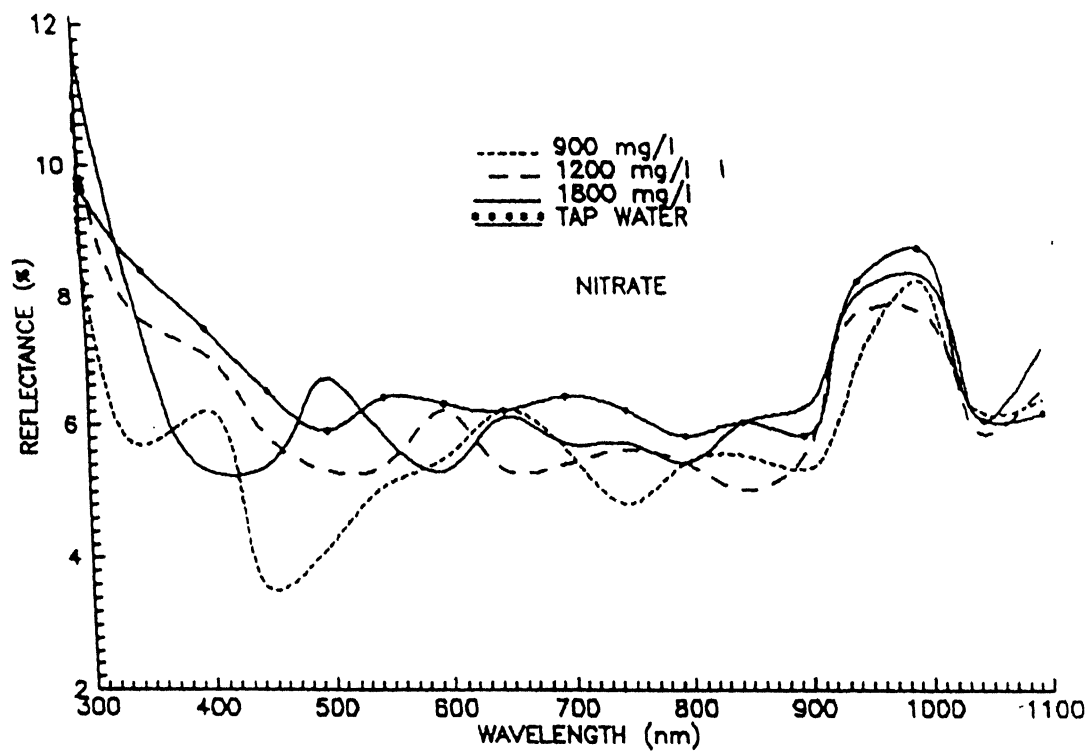


Fig 5.12 Spectral reflectance of nitrate containing water sample with varying concentration at 30°C

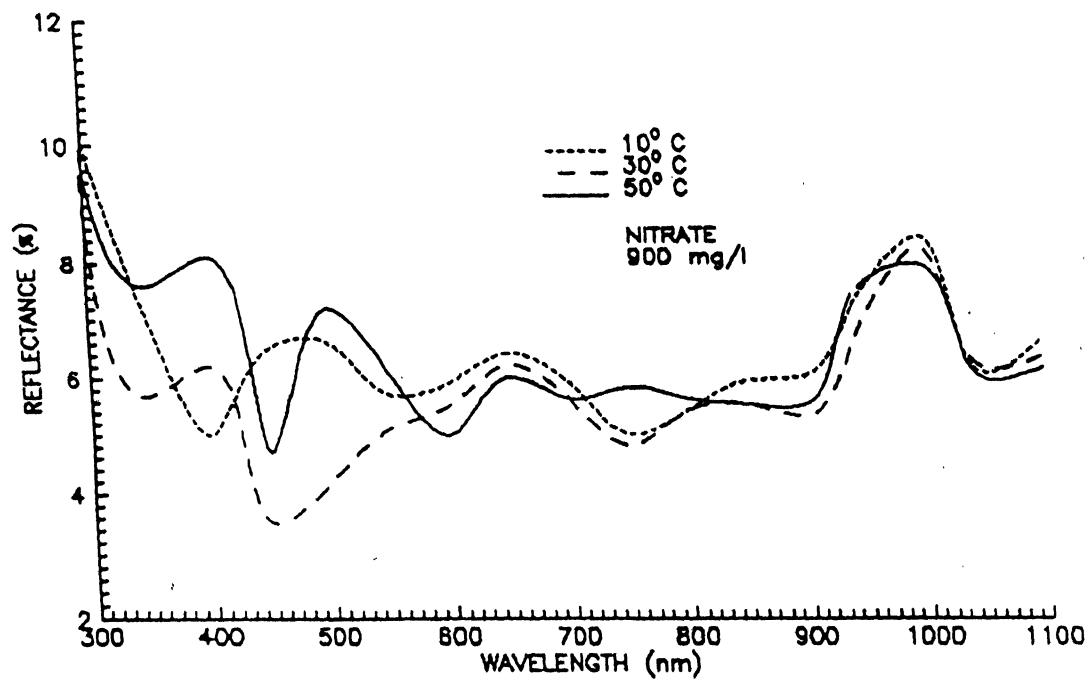


Fig 5.13 Spectral reflectance of nitrate containing water sample with varying temperature

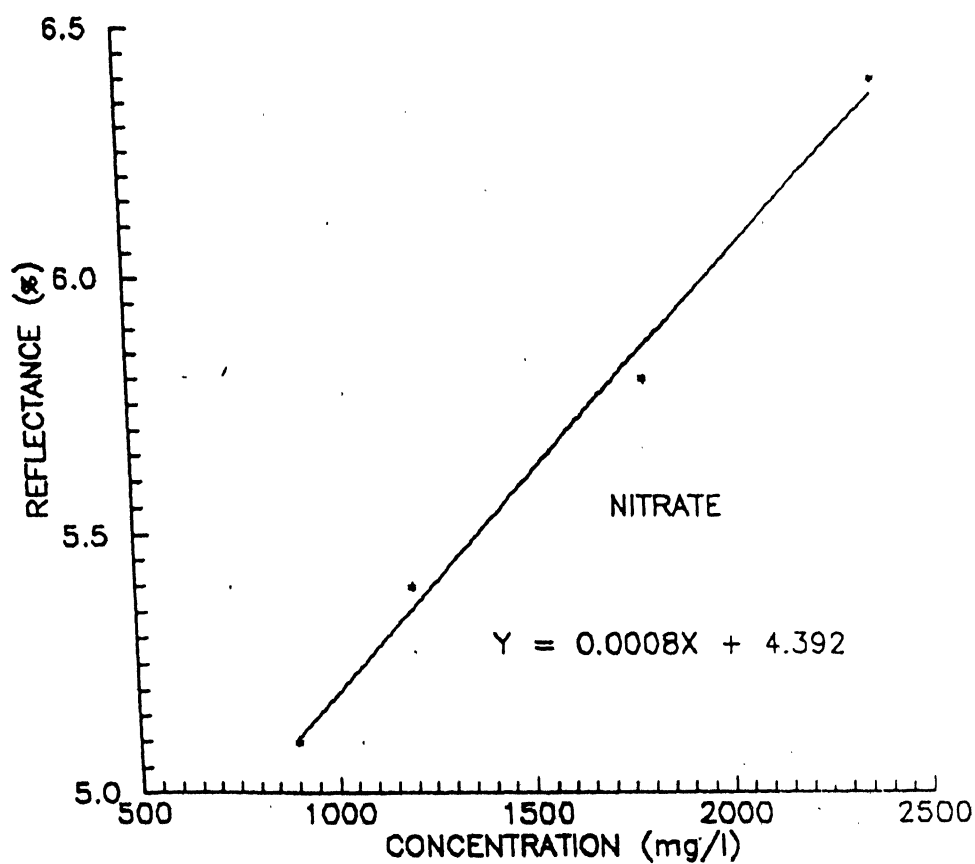


Fig. 5.14 Variation of reflectance of water with nitrate concentration at wavelength 550 nm

increase of reflectance values with the increase of phosphate concentrations. The effect of phosphate concentrations in water is found to be almost insignificant in the wavelength range 550 to 1100 nm. Some characteristic features of the reflectance curves are seen in the wavelength range 300 to 550 nm. In this range, the reflectance value is found to be lower for phosphate concentration of 600 mg/l. The reflectance curves for 900, 1200 and 2400 mg/l are characterized by maxima and minima peaks in the wavelength range 300 to 500 nm. The reflectance curves for tap water is clearly distinct from the reflectance curves of water samples with varying phosphate concentrations. The effect of temperature on the spectral reflectance of water with 900 mg/l phosphate concentration is shown in the fig (5.16). The effect of temperature shows characteristic temperature variation in the wavelength range 600 to 750 nm, in this range the significant reflectance contrast is seen (fig 5.16). The reflectance of the water containing 900 mg/l is found to increase with the increase of temperature from 10 to 50° C which shows a very systematic behavior. On the contrary reflection curves for varying temperatures show very un-systematic behavior in other wavelength ranges except wavelength range 600 to 750 nm.

Reflectance with varying concentrations of phosphate at the wavelength 450 nm is found to show a linear relation of reflectance with phosphate concentration (fig 5.17). The regression analysis of reflectance for varying phosphate concentrations has given following empirical relation

$$Y = 0.0017X + 2.827 \quad (5.6)$$

The above empirical relation is valid for the phosphate concentrations in the range 500 to 2500 mg/l.

5.9 Spectral response of sulphate contamination

Spectral reflectance water samples with sulphate concentrations 900, 1200 and 1800 mg/l are found to be uniform in the wavelength 300 to 1100 nm as shown in the fig (5.18). However, some characteristic features of reflectance is seen with varying

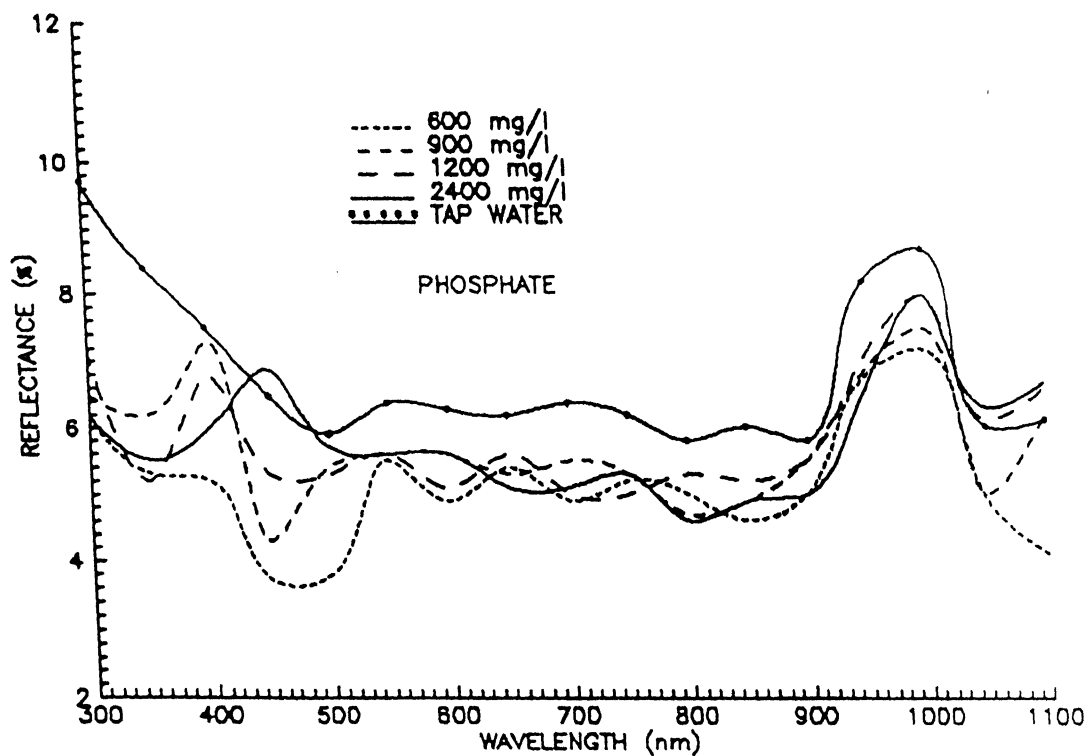


Fig. 5.15 Spectral reflectance of phosphate containing water sample with varying concentration at 30°C.

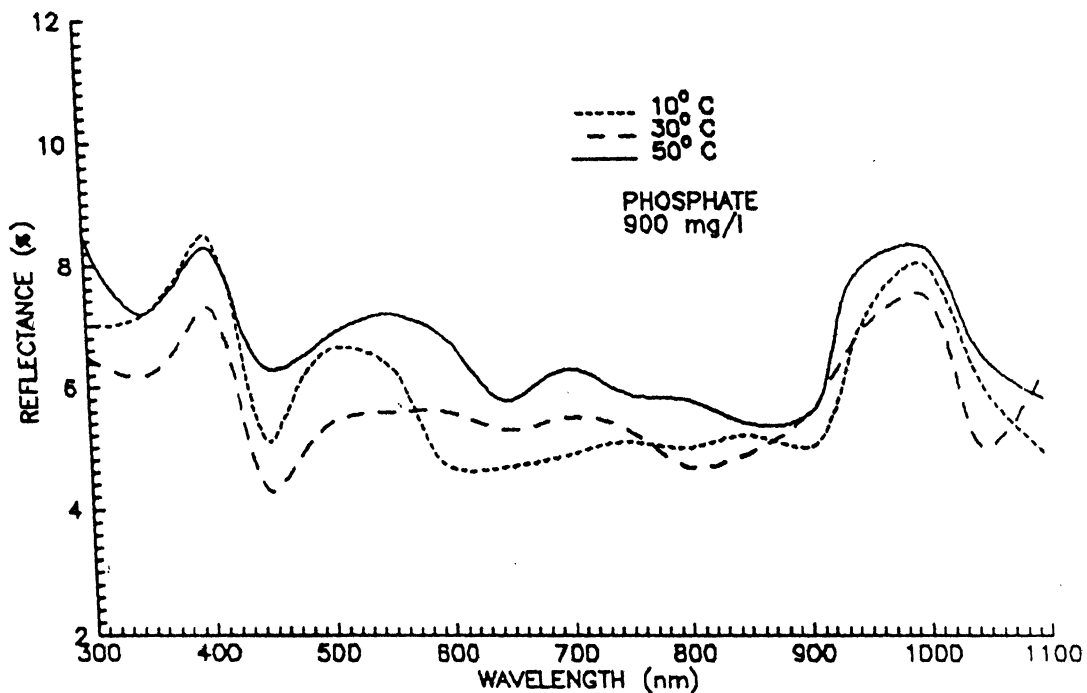


Fig. 5.16 Spectral reflectance of phosphate containing water sample with varying temperature

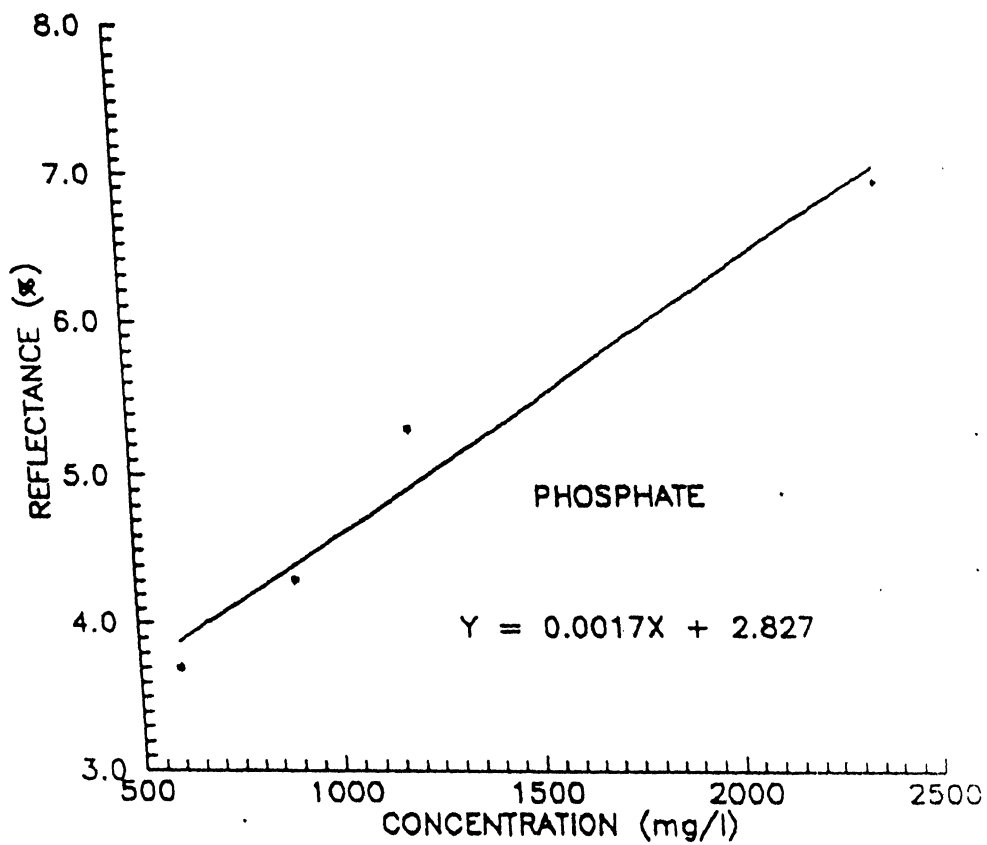


Fig 5.17 Variation of reflectance of water with phosphate concentration at wavelength 450 nm.

concentrations of sulphate in the wavelength range 500 to 620 nm. In this narrow wavelength range, the reflectance is found to increase with the increase of sulphate concentrations. Slight shift of peak towards lower wavelength is seen with the increase of sulphate concentrations. In the lower wavelength range 300 to 650 nm, the higher sulphate concentration is characterized by the higher reflectance with sharp maxima peak. In this wavelength range the high sulphate concentration (1800 mg/l) shows higher reflectance compared with the tap water (fig 5.18).

The effect of temperature on the spectral reflectance curves of sulphate concentration 900 mg/l is shown in fig (5.19). The significant effect of temperature on the reflectance of sulphate concentration of 900 mg/l is seen in the wavelength range 500 to 850 nm. With the increase of temperature, the frequency of maxima peaks are found to increase and are very pronounced. In the wavelength range 300 to 450 nm, the effect of temperature is found to be very distinct and the reflectance is found to increase with the increase of temperature (fig 5.19). The reflectance is found to show linear behavior with the increase of sulphate concentrations. The reflectance is found to follow following linear relation with the sulphate concentrations (fig 5 20).

$$Y = 0.0023X + 3.73 \quad (5.7)$$

The above reflectance relation is valid for the sulphate concentrations in the range 900 to 2400 mg/l.

5.10 Comparative study of spectral responses

For sake of comparison, in the fig (5.21) we have shown reflectance of various type of contaminates at concentration of 2400 mg/l in the wavelength range 300 to 600 nm. A slight change in reflectance value is seen for various type of contaminants. All types of contaminants show maxima and minima peaks which correspond at a particular wavelength (fig 5.21).

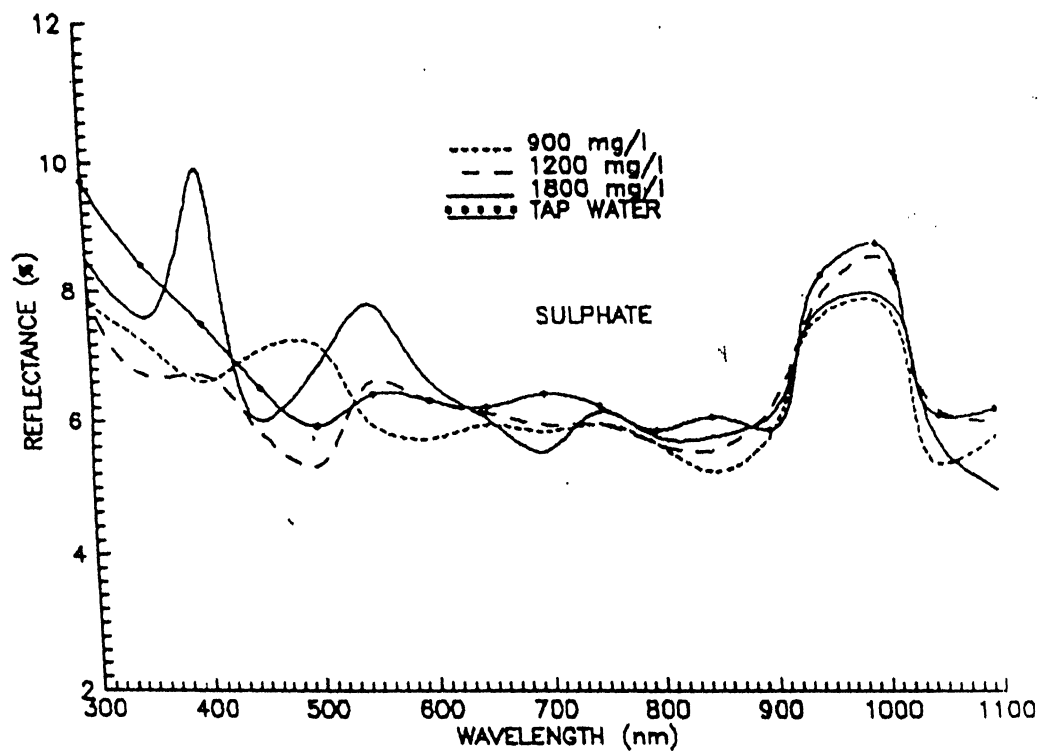


Fig. 5.18 Spectral reflectance of sulphate containing water sample with varying concentration at 30°C.

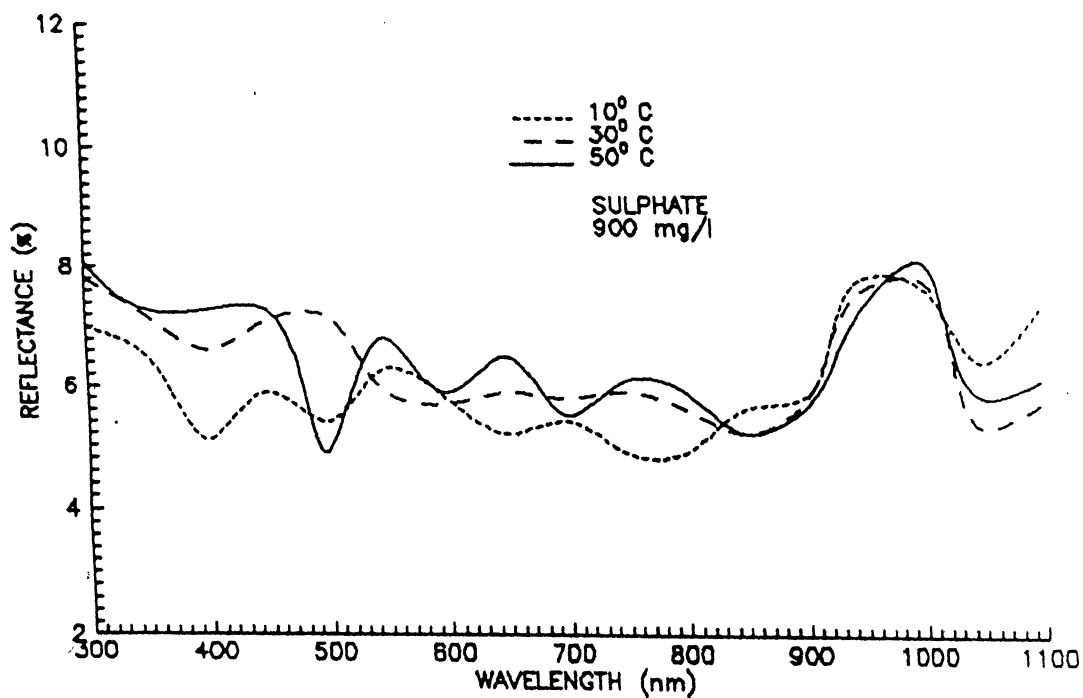


Fig. 5.19 Spectral reflectance of sulphate containing water sample with varying temperature

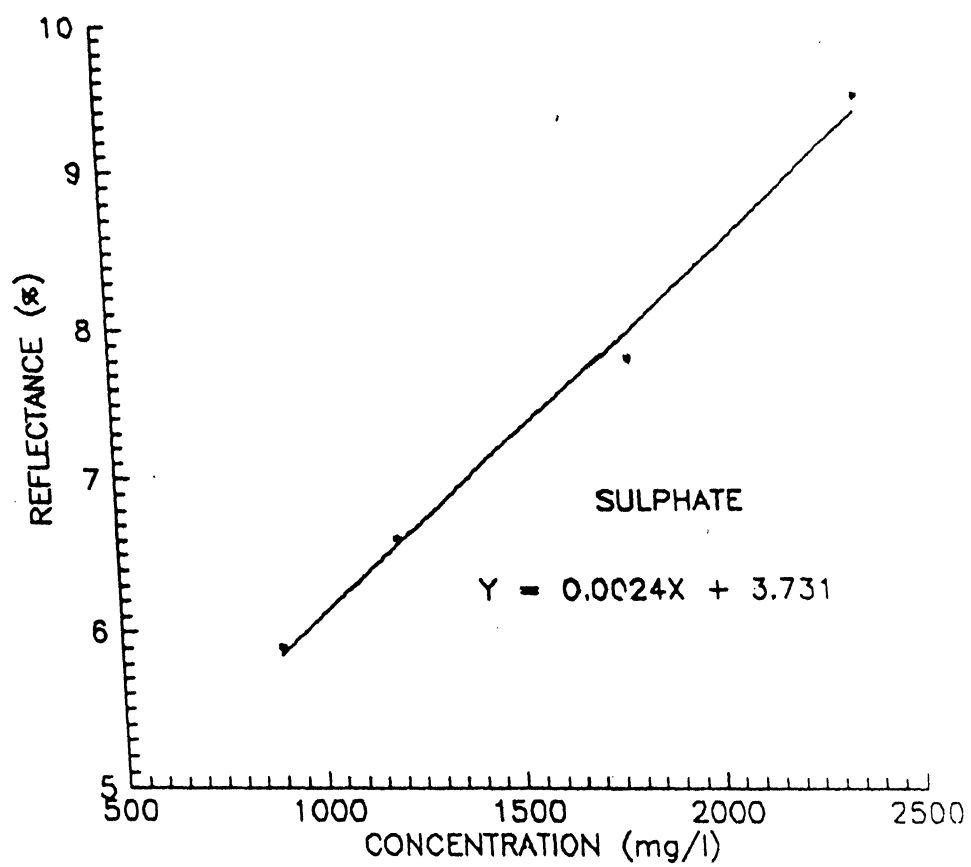


Fig 5.20 Variation of reflectance of water with sulphate concentration at wavelength 550 nm

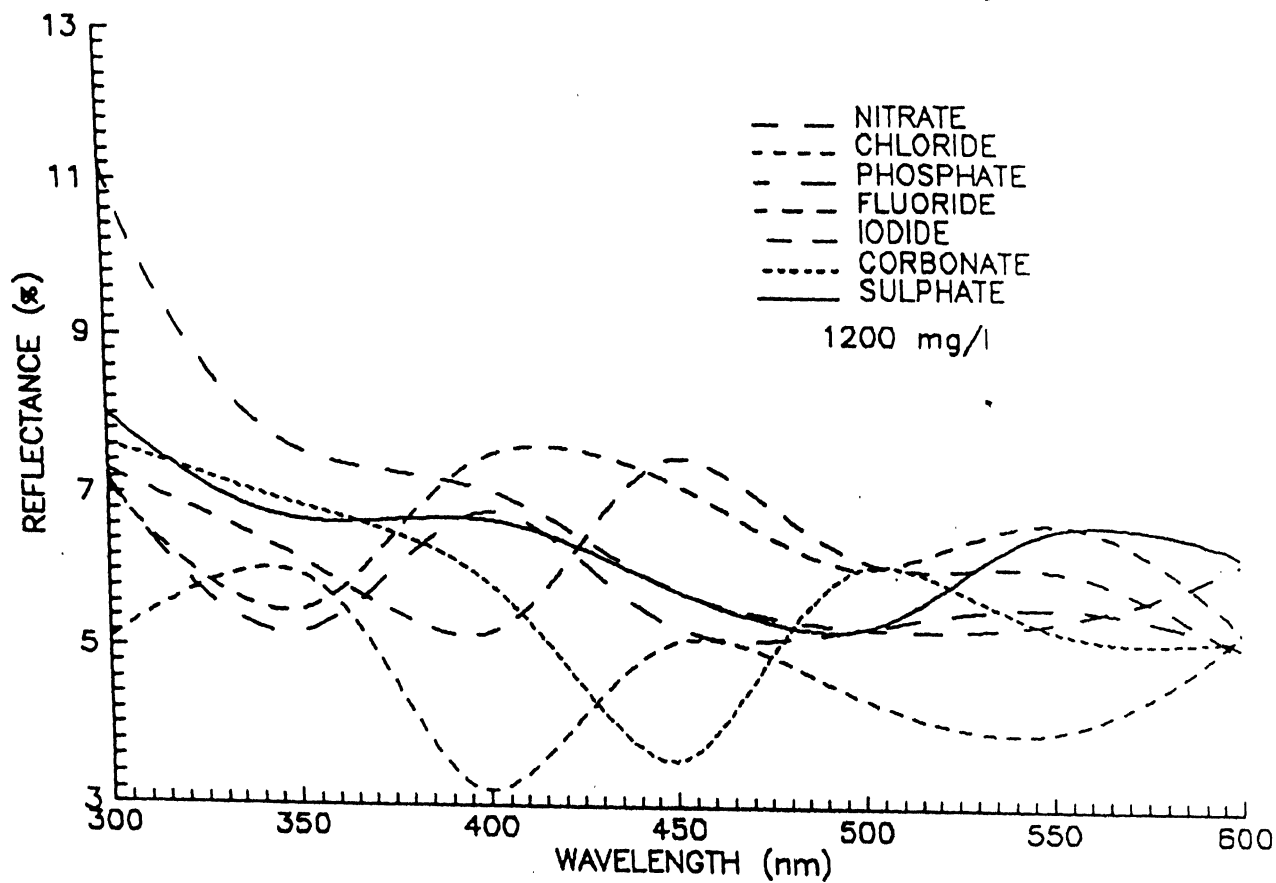


Fig 5.21 Spectral reflectance of different types of dissolved solids with 1200 mg/l at 30° C

5.11 Ganga water sample

Ganga river receives domestic and industrial waste water from about 100 large and small cities and towns during its 2525 km long journey. The water quality of the river Ganges has profound effect on almost 33 percent of India's population. Ganga river is the source of water supply, irrigation, industry, recreation and religious activities. Economic and rapid quantitative techniques for monitoring and measuring water quality are needed for adequate water management.

Remote sensing technique has proved to be a potential tool to meet this need and can be used to collect rapid and reliable data for a better quality interpretation and management of water resources. In the present study, water samples have been collected from Ganga river at three different places, Bramhawart, Druvitla and Hari-Dham near Bithour

5.11.1 Suspended solids in Ganga water

The amount of suspended solids present in the water samples collected from Ganga river has been measured in the environmental engineering laboratory. The experimental procedure is given in Chapter IV. The amount of suspended solids have been measured in mg/l which is given in table (5.1).

Table (5.1)

Location of water samples	Suspended solids concentration (mg/l)
Bramhawart	250
Druvitla	210
Hari-Dham	42

The above table shows that the Ganga water collected at Bramhawart is haracterized by higher amount of suspended solids and the water sample at Hari-Dham has lesser amount of suspended solids.

5.11.2 Spectral response of suspended solids

The incident energy on the water surface is reflected, absorbed and transmitted. In clear water the transmitted energy is greater and in turn the reflected energy will be reduced. Due to the presence of suspended solids, the transmitted energy will be greatly reduced and, depending on the properties of the suspended solids properties to absorb the energy, the reflectance energy will vary. Reflectance is not only the function of suspended solids concentration level but also a function of the properties of the sediment present (Novo et al., 1989; Bhargava and Mariam, 1990), environmental influences (Curran and Nova, 1988) and viewing geometry (Nova et al. 1989).

From the figures (5.22) and (5.23), it is seen that the reflectance increases with the increase of suspended solid concentrations in the wavelength range 300 to 1100 nm which shows low reflectance. Water samples at three sites Bramhawart, Druvtila and Hari-Dham contain respectively 250, 210 and 42 mg/l of suspended solids. We have found higher reflectance contrast between water samples collected at Hari-Dham and Bramhawart and Druvtilla in the wavelength range 300 to 1100 nm at 30° C. The reflectance contrast between water samples collected at sites Bramhawart and Druvtila is found to decrease which is consistent since the contrast between suspended solids present in these samples are also low. In the wavelength range 300 to 600 nm, reflectance curves show characteristic peaks. The effect of increase in temperature on the spectral reflectance is shown in fig (5.22). For higher temperature and higher suspended solids the reflectance shows low reflectance (for two locations Bramhawart and Druvtila) and lower suspended solids samples show decrease in reflectance at higher temperatures in case Hari-Dham water sample. However, the sharp reflection peaks are seen at 30° C and are not found to be pronounced at 50° C.

In fig (5.24) we have shown clearly the effect of increase of temperature on spectral reflectance at three sites. In case of water samples from Druvtila and Bramhawart,

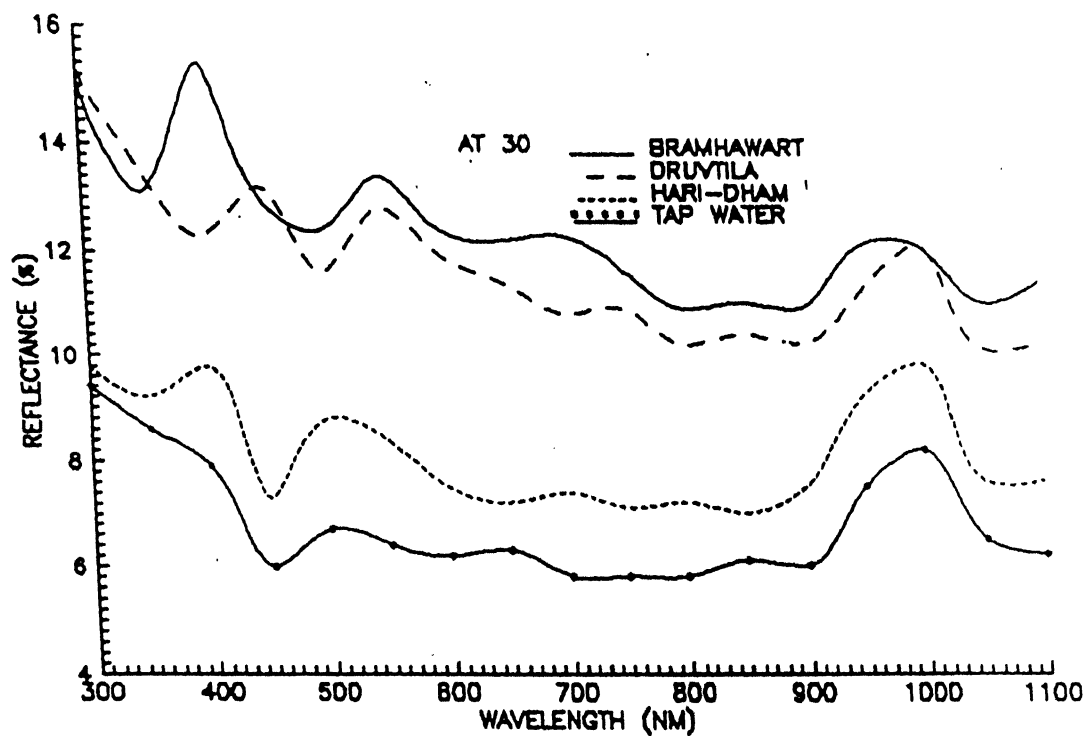


Fig 5.22 Spectral reflectance of Ganga water samples at 30° C

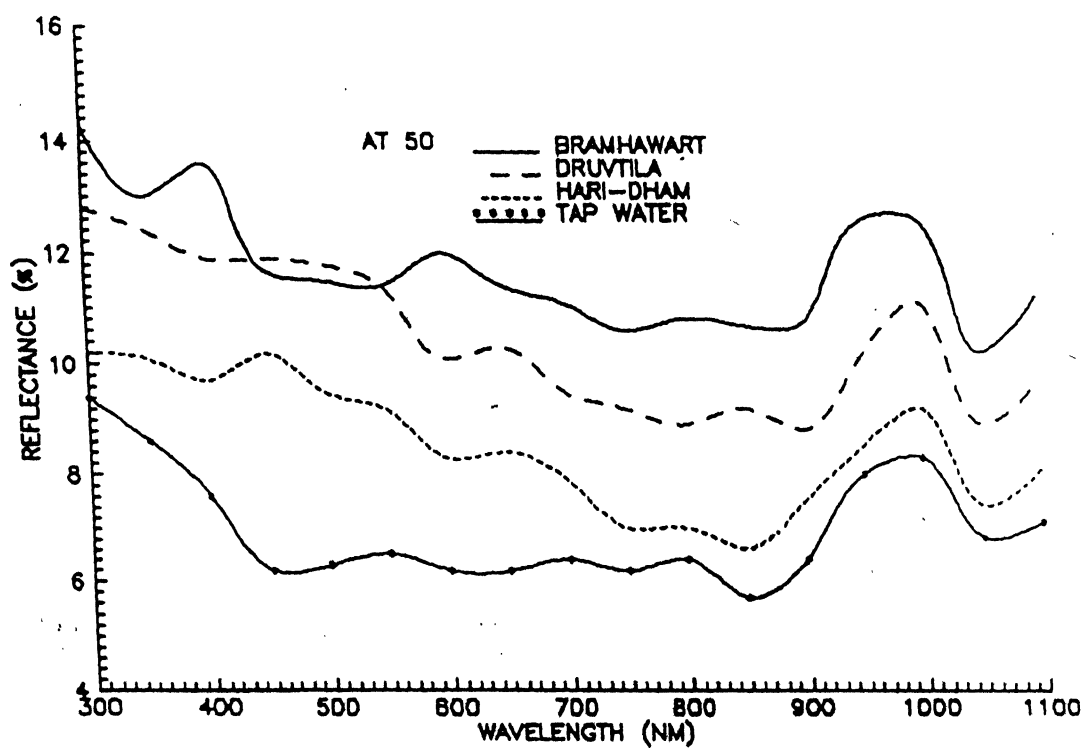


Fig 5.23 Spectral reflectance of Ganga water samples at 50° C

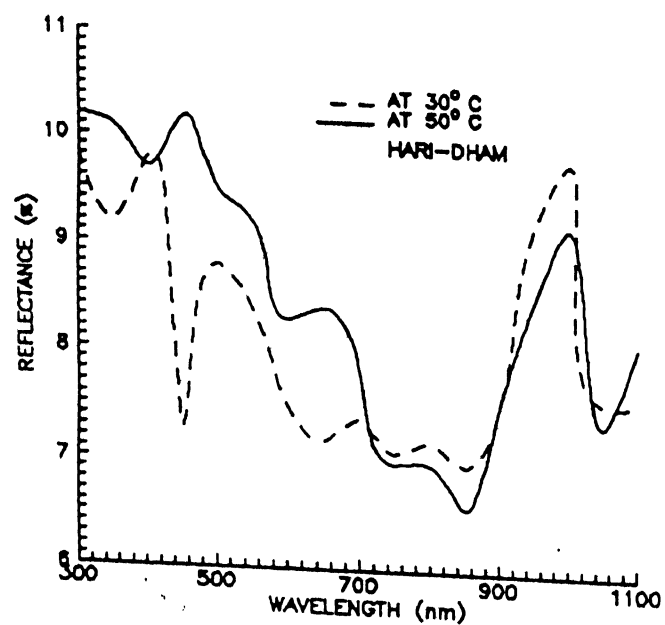
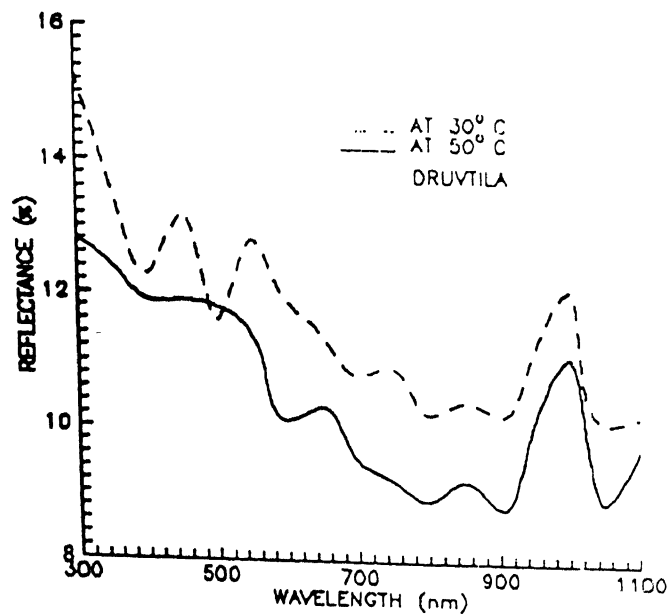
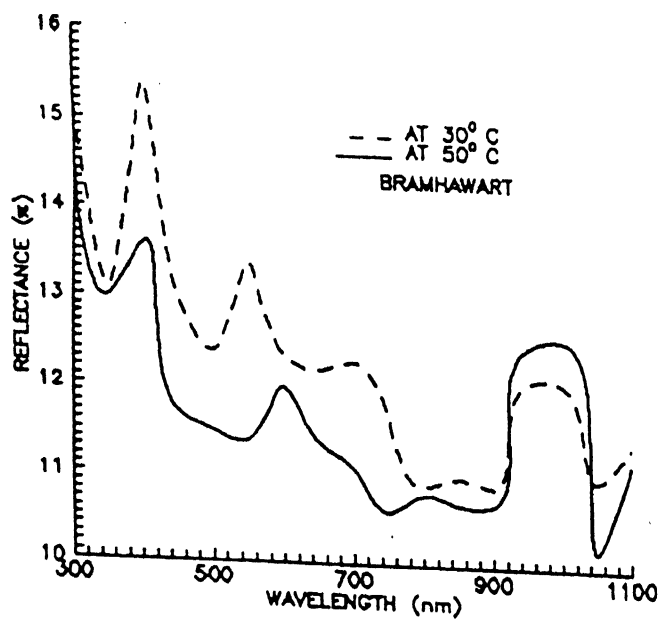


Fig 5.24 Spectral reflectance of Ganga water samples at different places with varying temperature

reflectance shows lower reflectance values at higher temperature whereas water samples from Hari-Dham shows higher reflectance value at higher temperature of 50° C. The magnitude of reflectance is found to show higher amount of suspended solids.

5.11.3 Empirical relations

The empirical relationship between suspended solid concentrations and reflectance at wavelengths 750 and 800 nm, is developed using regression analysis. The general relationship can be represented by the following equation.

$$S_s = C_1 R + C_2$$

where S_s is suspended solid concentration, R is reflectance in percentage and C_1 and C_2 are regression coefficients. The linear regression curves are plotted for the three water samples collected in Ganga river at different temperatures. Fig (5.25) shows the linear regression curves for wavelengths 750 and 800 nm at 30° and 50° C. The correlation coefficients for these three water samples are given in table (5.2).

Table (5.2)
The correlation coefficients of Ganga water

Ganga water	Temperature (° C)	Wavelength (nm)	C ₁	C ₂
	30°	750	0.022	6.17
		800	0.018	6.45
	50°	750	0.016	6.24
		800	0.016	6.18

Using the information given in the table (5.2) we can predict the amount of suspended solid concentrations if we get the reflectance value at the wavelengths 750 or 800 nm.

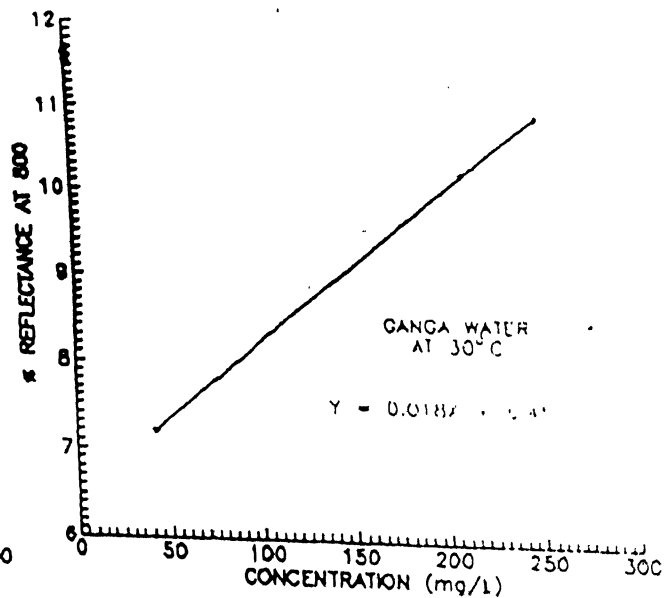
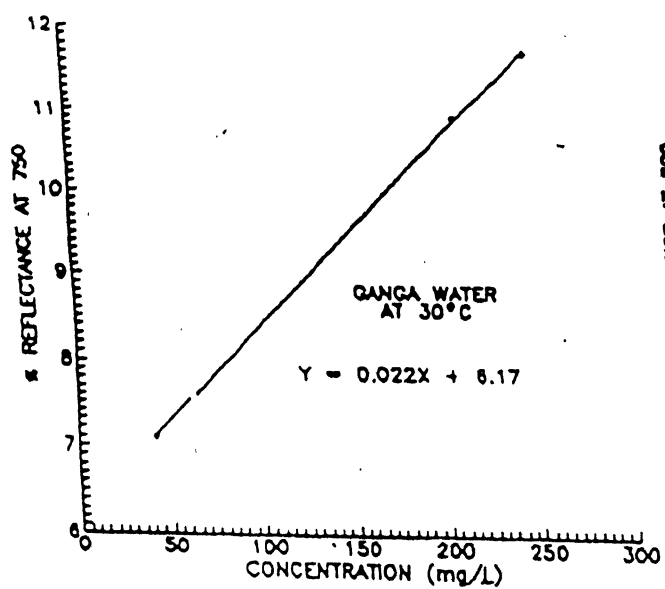
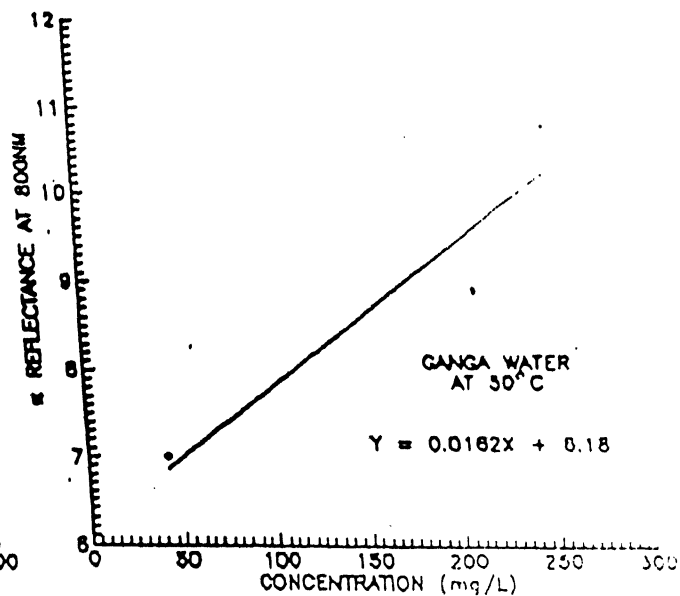
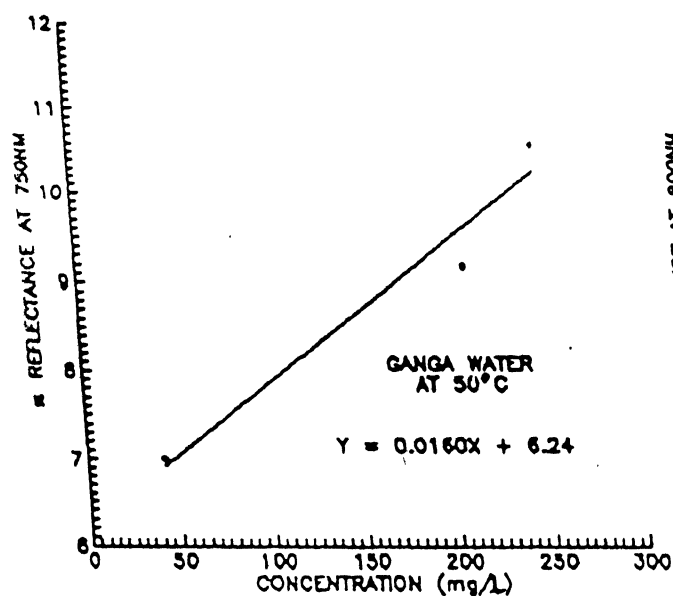


Fig 5.25 Variation of reflectance with suspended solid concentrations at 50°C and 30°C

Chapter VI

Conclusions

The spectral reflectance has been measured for different types of salts with varying concentration and also for Ganga water using spectrophotometer. Following conclusions have been drawn from analysis behavior of spectral reflectance curves.

- i) The measured reflectance at 30^o C shows characteristic behavior for the salt contaminations and these are strongly dependent on the wavelength.
- ii) The variation of reflectance measured at 30^o C with varying concentrations of carbonate is found to be highly wavelength dependent and in the range 300 to 500 nm reflectance increases with the increase in carbonate concentrations. Following empirical relationship between reflectance and carbonate concentrations at 400 nm is found which.

$$Y = 0.0010 X + 4.69$$

- iii) The reflectance curves of chloride concentrations measured at 30^o C show characteristic nature specially in the wavelength range 300 to 700 nm. In the wavelength range 700 to 900 nm the variation of reflectance of chloride concentrations is constant with wavelength. A mathematical relationship is obtained between reflectance and chloride concentrations at 750 nm, which is given by the following equation.

$$Y = -9.5808E-8 X^2 + 0.00064 X + 3.828$$

The reflectance and chloride concentrations can be predicted from the above equation at 750 nm.

- iv) The variation in reflectance measured at 30^o C with varying fluoride concentrations is not uniform in the wavelength range 300 to 1100 nm. It has been found that the reflectance becomes insensitive after some optimal limit of fluoride concentrations. The variation of reflectance with temperature has been found almost same except in

wavelength range 400 to 550 nm. The empirical relation has been found at 400 nm, which is given by the following equation

$$Y = 0.00233 X + 4.7$$

v) The nature of spectral reflectance for varying iodide concentrations at 30° C has been found to be very similar in the wavelength range 300 to 500 nm. In the wavelength range 700 to 900 nm curves of varying concentrations of iodide and tap water shows significant contrast. The effect of temperature on reflectance has found to be negligible. Following empirical relations has been found at 400 nm.

$$Y = 0.0025 X + 5.58$$

vi) Spectral reflectance has been found sensitive to nitrate concentrations in the wavelength range 300 to 600 nm at 30° C. In the wavelength range 450 to 550 nm reflectance increases with concentrations. The nature of reflectance curves has been found to be similar with varying temperatures except in the wave length range 350 to 500 nm. Following empirical equation has been found between nitrate concentrations and reflectance at 550 nm.

$$Y = 0.00084 X + 4.39$$

vii) The variation of spectral reflectance at 30° C with phosphate concentrations is almost negligible in the wavelength range 550 to 1100 nm. In the wavelength range 500 to 900 nm tap water can be discriminated with phosphate concentration because of higher reflectance. In the wavelength range 550 to 750 nm, the reflectance is found to increase with the increase of temperature. Following empirical relation has been found between reflectance and phosphate concentrations at 450 nm wavelength.

$$Y = 0.0017 X + 2.82$$

viii) The nature of reflectance of sulphate is almost similar in all wavelengths for all concentrations except at higher concentrations sharp peaks are seen. In the wavelength range 300 to 450 we have found increase of spectral reflectance with temperature. The

empirical relation at 550 nm wavelength between sulphate concentrations and reflectance is given by.

$$Y = 0.0023 X + 3.73$$

ix) The spectral reflectance increases with increase of suspended solid concentrations of Ganga water in the wavelength range 300 to 1100 nm. The water samples with higher suspended solids show low reflectance with the increase in temperatures. Water samples with less suspended solids show high reflectance with the increase in temperatures. The empirical relation has been found at wavelength 750 and 800 nm for two different temperatures 30° and 50° C.

$$Y = 0.016 X + 6.24 \quad \text{at } 50^{\circ} \text{ C for wavelength } 750 \text{ nm}$$

$$Y = 0.016 X + 6.18 \quad \text{at } 50^{\circ} \text{ C for wavelength } 800 \text{ nm}$$

$$Y = 0.022 X + 6.17 \quad \text{at } 30^{\circ} \text{ C for wavelength } 750 \text{ nm}$$

$$Y = 0.018 X + 6.45 \quad \text{at } 30^{\circ} \text{ C for wavelength } 800 \text{ nm.}$$

The present study shows the characteristic features of spectral reflectance of varying types of contaminants in the wavelength range 300 to 1100 nm. The results presented in this thesis show the appropriate wavelength ranges where various types of concentrations can be quantitatively evaluated. The present results will be useful in the proper selection of spectral bands for identifying the type of contaminations and their qualitative evaluation. It has been found that the spectral reflectances are very much sensitive to the amount of suspended solids present in the Ganga river water. The present study shows that a detailed data base of reflectance be prepared from the water samples at various sites along Ganga river which will be very useful in developing an empirical relation. Such data base will be of immense use in quantitative and qualitative determination of water quality from Ganga and other rivers from the analysis of spectral and spatial modes remote sensing data taken from airborne and satelliteborne sensors.

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